SCHOOL TECHNOLOGY SERIES

ELEMENTS OF ELECTRICAL ENGINEERING

A TEXTBOOK FOR TECHNICAL SCHOOLS

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Foreword

It is a truism that we live in an age of technology. Our four successive Five-Year Plans are all directed towards the development of a technological society. To this end, we have to train a multitude of technicians who will set up plants, and design and produce machines, tools and implements to bring to fruition the well-considered Plans of an informed leadership.

The National Council of Educational Research and Training is particularly concerned today with education at school level. Technology is one of the fifteen subject-fields in which the National Council, on the advice of its Central Committee on Educational Literature, is bringing out textbooks. In agreement with public feeling and recent recommendations of the Education Commission report, the Council is producing educational materials for vocationalized secondary schools. The present publication on electrical engineering is an earnest of its plan of work to provide the schools with model textbooks. This is one of the four textbooks that have been and are being prepared under the direction of Prof. K. B Menon, Head of the Department of Electrical Engineering, Indian Institute of Technology, Kharagpur The other three books in the series are *Engineering Drawing, Workshop Practice* and *Elements of Mechanical Engineering.*

Electrical Engineering is an introductory book for students in the higher classes of Indian secondary schools, who offer engineering as an elective subject and for students of specialized technical schools. The book will also be useful in the earlier stages of the polytechnic diploma course. The aim of the book is to present an over-all view of the major areas in the subject without entering into specialized details required for advanced studies. Its purpose is to develop in the students an understanding of the basic principles of electrical engineering. The text is in simple English and all technical terms have been defined with clarity.

The National Council wishes to thank the author of the book, Dr. S. P. Ray Chaudhuri for having undertaken this work, and Prof. K. B Menon who has directed the whole project of textbooks in

technology. The Council is also grateful to Dr S. R. Sen Gupta, Director, Indian Institute of Technology, Kharagpur, for the facilities provided for the completion of the project.

The National Council hopes that all students of technology at secondary level and students of specialized technical schools and polytechnics will benefit from this book. Suggestions from teachers and others interested in electrical engineering are welcome, and will be considered when the book is revised.

L. S. Chandrakant

Contents

Introduction

In the present age Electricity has become so much a part of our everyday life that we cannot even think of a day without it Try to imagine your living today without electricity, doing without any electric lights, fans, radios, televisions, refrigerators, indeed, without any electric appliance of domestic use You would have no telephone, no telegraph, no electric-train and no automobiles When you think of all this, you at once realise how much ease and happiness electricity has brought into our lives.

Electricity plays a very important role in *communications* People can communicate with one another within seconds or minutes, not only in this world but also from outer space. This communication is possible through telegraph, telephone, radio and television, teleprinter, and other signal-transmitting devices. Information about weather and ionospheric conditions about the earth can be obtained on earth through the remote controlled artificial earth satellites, We hope that in future when men land in other planets we will have inter-planetary communication with the help of electricity.

In transportation, too, electricity can speed up movements of goods, as also of people from one place to another. In fact, all vehicles plying on land, sea or in air need electricity for their operation and control Electrical devices also help in the safe and efficient working of these transport-agents. Radar, for example, helps in safe landing and tracking of aircrafts, special lamps light the highways; strong electric lights help safe and fast driving of motor vehicles at nights.

Modern *Industry*, both heavy and light, can produce goods at a high rate and with the utmost economy by using electricity; for it can control production and manufacture with great ease and efficiency

So we see that electricity is useful in so many fields of our life. Then, the question arises: from where do we get electricity? Since electricity has to do some work, we need *electrical energy*. This energy is provided by the generators of electricity These generators, in turn, may get their energy from various substances like coal, oil, radio-active materials, and water stored in a reservoir and so on When we talk about energy, we merely refer to the capacity for doing work or *how much work* can be produced. But this is not enough; it is also necessary to know at *what* rate some

given amount of work can be performed. This rate of doing work is known as power. We would rather call it *electrical power*, i.e , the rate at which the electrical energy can be produced or consumed. To illustrate the point, a man must have food to be able to do some work; a stronger man can do more work in a given time than a weaker man The man in this case derives his energy from food, and a stronger man with his stronger muscles is more powerful than the weaker man The man himself may be compared to a generating machine. The main types of plants which make electrical energy available for use are: the hydro-electric power plant, steam-electric power plant, and the atomic-electric power plant, using as their sources of energy water, coal or oil or gas, and radioactive substances respectively. These plants are also known as generating stations. In hydro-electric power plants, the potential and kinetic energy of water is utilised to drive a turbine or water wheel which is coupled with a generator of electricity. In steam-power plants we have the latent energy in the coal or oil released by burning it. The resulting heat evaporates water in a boiler and produces steam. The steam drives a turbine or a steam engine coupled with a generator The oil may burn in an internal combustion engine also and drive the generator coupled with it. In the atomic power plant, atoms are split to produce the heat which is conveyed to a steam-power plant.

The electrical energy produced in the generating stations must reach consumers at various distances. This is achieved by transmission lines and distribution networks spread over the country. You must have heard the word "grid", like the D.V.C. and other state grids and the All-India "super-grid". They are the main transmission and distribution networks to which the various generating stations and the consumers are connected. The transformer is a very important piece of equipment needed in a grid This can raise or lower the voltage at any point as necessary Other equipments of importance are the circuit interrupting devices, protective devices against abnormal conditions of operations, etc

Electricity is utilised by the consumers in the form of heat, light and mechanical energy. Heat is required in many chemical, steel and other industries, and also by domestic consumers. Light and Mechanical power are needed by several types of consumers. Large amounts of heat are produced in electric furnaces. Light is produced by various kinds of filament and discharge lamps. Mechanical energy is produced by electric motors. The sizes of all these energy consuming devices are determined by power.

It is difficult to predict the future of electricity. Engineers and technicians are hard at work seeking to make electricity a tool in the hands of man for attaining the goal of a still better, brighter and happier life.

CHAPTER 1

Electric Circuits

IN day-to-day life one hears quite often the term "electricity" used to imply its various effects In fact it is only used to indicate electrical quantities like *electric current*, *voltage*, *electrical power* and *electrical energy* Each of these quantities is different from the rest, and it is necessary to understand the meaning of each before proceeding further with the subject

1-1. Electric Current

It is well known that all substances contain a large number of negative charges called *electrons*. These are the smallest particles of matter, and are responsible for the causes and effects of electricity. Most of these electrons are firmly bound to the respective positive nuclei called *protons*. The rest of the charges, which are free and unattached, move in a given direction when a force, called *electric force*, is properly applied The motion of these negative charges, caused by the application of electric force, is known as electric current.

The *electric circuit* is the path that electric current takes as it goes through the wires. This path must be complete; otherwise, there will be no flow of electric current A complete electric circuit is usually composed of four main parts:

(i) the source of electrical energy which provides the necessary electric force or electric potential, as it is very often called (say, a cell or battery),

(ii) the conductor or path for electric current;

(iii) the controlling device or *switch*;

(iv) the *load* where the electrical energy is consumed.

Generally, there may be one or more of these four parts in an electric circuit Fig 1 1 shows a complete electric circuit

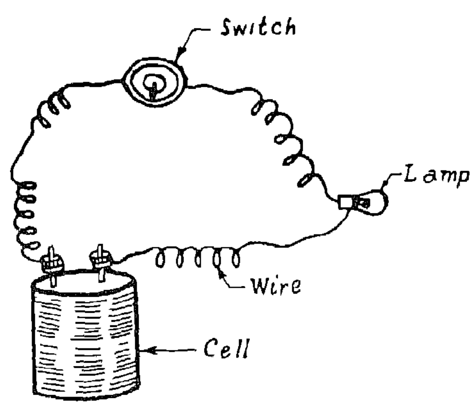


Fig. 1.1. An Electric Circuit

1-2. Theory of Current-flow, E.M.F.

The very small free electrons exist in large numbers in all substances, belonging to the class of metals, but are especially abundant in such metals as copper, aluminium, silver, gold, nickel and tungsten Before an electric potential is applied on the circuit (the electric potential is usually referred to as the voltage), the electrons in the conductor move about very slowly at random so that the net forward motion is zero But as soon as a voltage is applied, the electrons begin to drift towards the *positive pole* of the voltage source. Note that the electron flow is *towards* the *positive terminal* of the source of supply, and not *from it*. However, the usual convention, which was established before the electron theory was known, is to believe that the current flows from the positive terminal of the source of supply. Although this is directly opposite to the actual state of the electron flow, several important rules of electro-magnetism (which will be explained later) were formulated on the basis of this convention These rules merely state the results of actual experiments connected with the subject. So long as the rules and the actions always agree, it is immaterial whether the rules are based upon the actual electron flow or an arbitrarily assumed flow. It is better, however, to retain the original convention which assumes current flow to be moving from the positive terminal of the source of supply into parts external to the source.

The source of supply, shown in Fig 1.2, which provides the necessary potential for producing an electric current is said to possess an *electro-motive force* (*E M F*). The E.M F may be obtained from various types of potential sources, like batteries or generators.

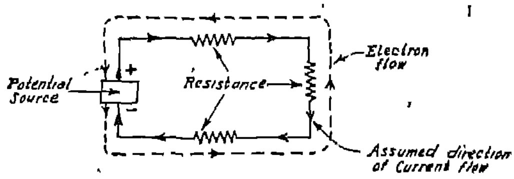


Fig. 1.2. Direction of the Flow of Electric Current

There are two general classes of potential source·

(a) the *Direct Current* or D C, and

(b) the *Alternating Current* or A C.

Let us deal with D C. first.

1-3. Conductors and Insulators

A conductor, or a conducting material, is a material through which electric current can flow easily, and which contains a very large number of free electrons The three best-known conducting materials are silver, copper and aluminium, but most metals are good conductors of electricity. Some gases, under certain conditions of operation, behave as conductors In fluorescent lamps, electrons flow through mercury vapour and argon gas to produce light. In neon signs, which are commonly used for displaying advertisements at night, electrons flow through neon gas or a mixture of neon and other gases.

The most commonly used conducting material is copper Aluminium also is used increasingly because it is lighter than copper. Other materials used as conductors are German Silver, Nichrome and other alloys.

As compared with conductors, materials known as *insulators* contain a very small number of free electrons. That is why when an insulator is placed across a potential source, very negligible current flows through it. Rubber, bakelite, polyethylene, porcelain, ebonite, paper, mica, etc., are good insulating materials. For all practical purposes, it is said, no current flows through insulators.

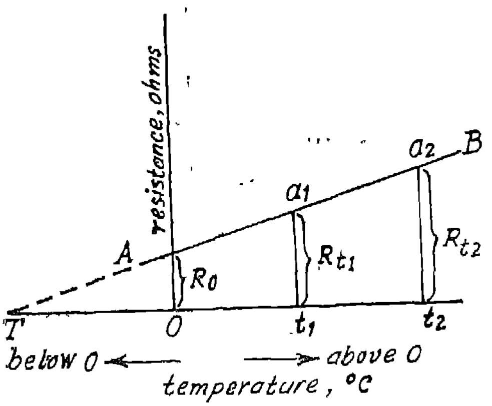


Fig. 1.3. Change of Resistance with Temperature

Most conductors used in electric circuits are covered with a kind of insulating material. Its purpose is to keep the metallic conductors electrically separated, and also to prevent them from touching the grounded structures, such as metallic pipes, poles, etc., which can carry current back to the source of supply that in most cases is grounded. The more common insulating coverings are cotton, silk, enamel, asbestos, rubber and polyethylene. A copper wire may have one, two or three layers of one or two of these insulating materials. Most insulating materials should not only be able to withstand the voltage to which they are subjected, but also have enough mechanical strength and capacity to withstand the high temperature that they are likely to be exposed to.

1-4. Ampere, Volt and Watt

It is necessary to have some units of current and potential difference or voltage in order to have some idea of the relative strengths of these quantities, when they vary in different cases.

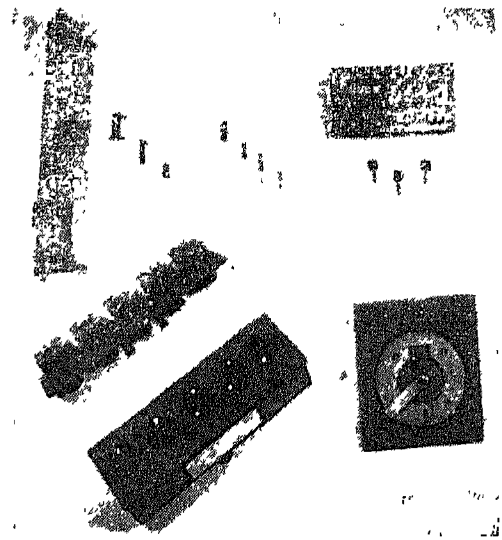


Fig. 1.4(a)

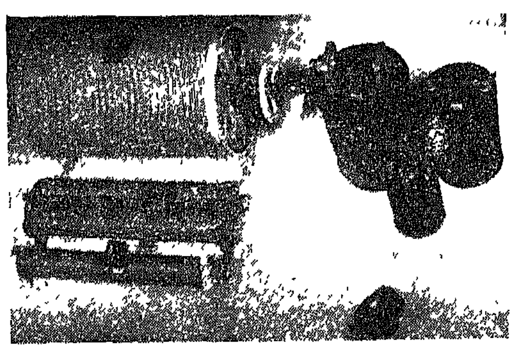


Fig 1.4(b)

Fig. 1.4. (a) and (b). Different Types of Resistors and Rheostats

The unit of current is the *ampere*, and the unit of potential difference is the *volt*. The letters A and V represent "ampere" and "volt" respectively. A complete definition of ampere, however, needs reference to a chemical effect of electricity, which will be explained later This effect is that when a current flows through a solution of metallic salt, it will deposit metal in one of the electrodes The ampere is that value of current which, passing through a solution of silver nitrate, deposits silver at the rate of 0 001118 grammes per second The instrument which measures current is called an *Ammeter*

The *watt* is the unit of electric power and is denoted by the letter W. The power in an electric circuit depends on both voltage and current and in a D. C. circuit this is obtained by multiplying these two quantities. Thus when I V causes a current of 1 A in a circuit, the power is 1 W. The instrument which measures power is called a *wattmeter*.

So the volt may be defined as that potential difference which, causing a flow of 1 A, gives a power of 1 watt

There are several terms that are used to denote what we have called "potential difference" (abbreviated as p.d.) They are· Potential, Tension, Pressure, Voltage and Electromotive Force These terms are not quite synonymous. The Electromotive Force, denoted by the letters E.M F., usually means the potential difference set up in a device for generating electricity; the actual pressure or p d. available for use from this device is called the pressure or voltage Very high voltages are often expressed in terms of a larger unit called *Kilo-volt*, which is equal to 100 volts, and is denoted by the letters KV Thus 132,000 volts is equal to 132 KV. The instrument which measures voltage is called a *voltmeter*.

1-5. Resistance, Ohm's Law

Every electric circuit opposes a current flow to some extent. This is felt by the limitation of current in the circuit, the extent of the limitation depending on the magnitude of this opposition. This opposing property of the circuit is known as *resistance* In general, the *resistance is defined as the property of a material that tends to oppose a flow of the current*, and the material itself is called the *resistor*

The current and voltage in a circuit are related by Ohm's Law. This law states that *if the temperature of an electric circuit is constant, the ratio of the steady voltage applied to it in volts to the steady current produced in amperes, is a constant quantity called the resistance of the circuit.* But there are some materials in which the ratio of the voltage and current is not constant for all ranges of voltages, and the Ohm's Law, as stated above, is not applicable to these materials. The unit of resistance is ohm. When a p.d. of 1 V causes a current of 1 A in a circuit, the resistance of the circuit is 1 ohm

So, if the circuit has a current of I amperes with a voltage of V volts across it, the resistance R of the circuit is given by

$$R = \frac{V}{I}$$

$$\text{or } V = IR$$

$$\text{or } I = \frac{V}{R} \cdot$$

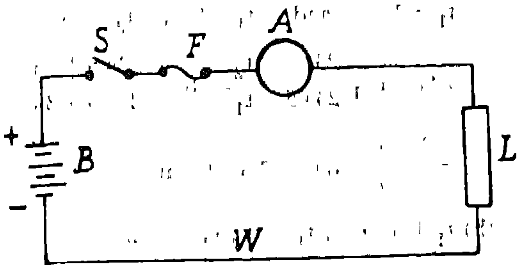


Fig. 1.5. A Circuit with Various Elements

To illustrate these formulae by numerical examples, suppose 4 A flows in a circuit at 220 V. The resistance is 220/4 = 55 ohms. Again, the voltage required to force 5 A current through a resistance of 45 ohms is 5 x 45 = 225 V. Further, if a voltage of 230 V is applied to a resistance of 115 ohms, the current will be 230/115 = 2A. The word ohm is often symbolically represented by Ω.

The resistance of any material in an electric circuit, which is of a homogeneous and symmetrical construction, depends upon four factors:

(a) Kind of material, (b) length over which the current flows, (c) the cross-sectional area through which the current flows and (d) the temperature of the material.

1-6. Resistivity

It has been found that at a given temperature the resistance (R) of a material is directly proportional to the length (L), and inversely proportional to the area (A), so that the resistance may be related to the length and area by

$$R = \rho \frac{L}{A}$$

where ρ is the constant of the proportionality known as the resistivity.

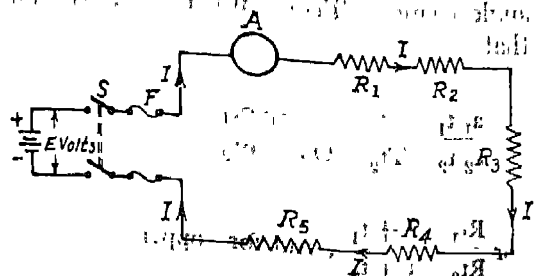


Fig. 1.6. A Series Circuit

If R is in ohms, L in cms, and A in sq. cms, then ρ is in ohm-cm units. The resistivity, ρ may also be defined as the resistance in ohms of the material, made in the shape of a cube of 1 cm side; and the resistivity is given as so much ohms per centimetre cube, abbreviated as ohm/cm^3. It should be carefully noted that a cubic centimetre of the same material, at the same temperature, will give different resistances for different combinations of length and area.

1-7. Effect of Change in Temperature

The resistance of all types of metallic wires that are used in electrical circuits increases as the temperature of the wires increases. The extent of increase for a given temperature rise depends on the kind of material of the wire.

If the resistance of a length of wire is plotted in a graph from the results of an experiment, as shown in Fig. 1.3,

the line AB will show the change in resistance with change in temperature. The extension of the line AB, as shown by the dotted line TA, represents the resistance at very low temperatures, which are not likely to occur in practice. The temperature T at which the resistance will become zero is -234.5° C for copper. From the two similar right-angle triangles Tt_1a_1 and Tt_2a_2 it is seen that

$$\frac{a_1 t_1}{a_2 t_2}=\frac{Tt_1}{Tt_2}=\frac{OT+ot_1}{OT+ot_2}.$$

or $\frac{Rt_1}{Rt_2}=\frac{T+t_1}{T+t_2}$, and for copper,

$$\frac{Rt_1}{Rt_2}=\frac{234.5+t_1}{234.5+t_2}.$$

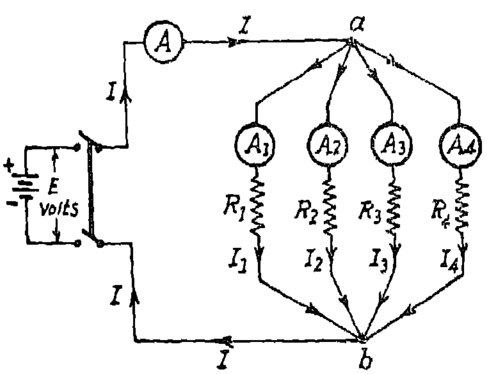


Fig. 1.7. A Parallel Circuit

If the resistance at the temperature is known, then the resistance at any other temperature can be calculated by using the relationship as given above.

Example: A coil of copper-wire has a resistance of 80 ohms at a room temperature of 30°C, (a) what will be its resistance at 75°C? and (b) at -20°C? (c) At what temperature will its resistance be 100 ohms?

Solution:

(a) $t_1=30^{\circ}C$ and $Rt_1=80$; $t_2=75^{\circ}C$

$$Rt_2=Rt_1\frac{234.4+t_2}{234.5+t_1}=80\times\frac{234.5+75}{234.5+30}$$

$$=\frac{309.5}{264.5}\times 80=93.5\ \Omega \text{ Ans.}$$

(b) $t_1+30^{\circ}C$, $Rt_1=80$, $t_2=-20^{\circ}C$

$$Rt_2=80\times\frac{234.5-20}{234.5+30}=80\times\frac{214.5}{264.5}$$

$$=64.8\ \Omega \text{ Ans.}$$

(c) $t_1=30^{\circ}C$, $Rt_1=80$, $Rt_2=100$

$$\frac{80}{100}=\frac{234.5+30}{234.5+t_2}$$

or $80\ (234.5+t_2)=100\times 264.5$

or $80\ t_2=100\times 264.5-80\times 234.5$

or $t_2=\frac{100\times 264.5-80\times 234.5}{80}$

$$=\frac{100}{80}\times 264.5-234.5$$

$$=330.6-234.5=96.1^{\circ}C \text{ Ans.}$$

The increase in resistance with increasing temperature is usually expressed in terms of another quantity known as *Resistance Temperature Co-efficient.* If R_1 is the resistance of a conductor at $t_1{}^{\circ}C$ and R_2 is the resistance at $t_2{}^{\circ}C$, then

$$R_2=R_1\left[1+\alpha_1\left(t_2-t_1\right)\right],$$

where α_1 is the resistance temperature co-efficient at $t_1{}^{\circ}C$. If α_2 is the co-efficient at t^2C, then

$$\alpha_2=\frac{\alpha_1}{1+\alpha_1(t_2-t_1)},$$

or $$\frac{1}{\alpha_2}=\frac{1}{\alpha_1}+(t_2-t_1).$$

Example:

The resistance of a coil wire at 20°C was 100 ohms After increasing the temperature of the coil to 26°C the resistance was found to be 103 ohms. Calculate (i) the resistance temperature co-efficient of the wire at 20°C and (ii) the co-efficient at 26°C.

Solution:

(i) We know that

$$R_2=R_1\,[1+\alpha_1(t_2-t_1)].$$

By substituting the values of R_1, R_2, t_1 and t_2 given in the problem, one can have

$$103=100\,[1+\alpha_1(26-20)]$$

or $$1+6\alpha_1=1{\cdot}03$$

or $$\alpha_1=\frac{0{\cdot}03}{6}=\cdot005 \text{ ohm/°C. Ans.}$$

(ii) $$\frac{1}{\alpha_2}=\frac{1}{\cdot005}+(26-20)=200+6$$
$$=206$$

or $$\alpha_2=\frac{1}{206}=0\,0048 \text{ ohm/°C. Ans.}$$

1-8. Resistors and Rheostats

Fixed resistors are the resistance-units made of suitable materials like carbon mixture or resistance wire which are used in electric circuits for varying current Although wires are necessary to inter-connect the various parts of an electric circuit, like resistors etc., the resistances of these wires are very small, and hence insufficient for controlling currents

Variable resistors are used where it is necessary to adjust the amount of resistance in a circuit. A resistor which has the means to vary its resistance is known as a rheostat. Fig. 1.4 shows the resistors and the rheostats. Rheostats are made of thin resistance wires wound on asbestos tubes, and the current that is allowed to flow through a rheostat depends on the cross-sectional area of the wire.

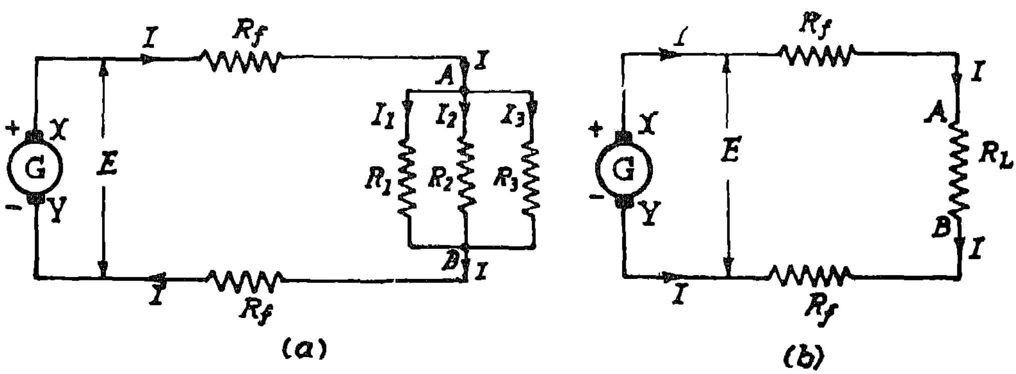


Fig. 1.8. A Series-Parallel Circuit and Its Equivalent

1-9. The Wire-table

A wire-table is useful to people in the electrical engineering profession, because with its aid one can readily find out various particulars, like diameter, cross-sectional area, the safe current-carrying capacity, resistance, etc. of wires of various commercial sizes and materials. Table 1.1 shows such a table. The size or cross-sectional area of a conductor is usually expressed in terms of a "Gauge Number", and it is known as "Standard Wire Gauge" (S.W.G.). The higher the Number, the lower would be the cross-section.

1-10. Resistances in Series and Parallel Circuits

All parts, like source of supply, connecting wires, control units, protective devices, meters and instruments, and the power-consuming devices of the electric circuit have resistances of different values. The most predominant part is the resistance of the power-consuming device called the load. The resistance of the other elements of the circuit, having insignificant values in comparison with the resistance of the load, is usually ignored. But when the resistances of some elements of the circuit cannot be neglected, they are combined for the purpose of calculation, necessary to determine the current, voltage and resistance in various parts of the circuit.

1-11. Series Circuit

When the various elements of a circuit are connected in such a way that the current leaving one of them must

Table 1.1

Wire-table for Hard-drawn Solid Copper Conductors for Overhead Lines

Size S.W.G.	Diameter mm.	Calculated area sq. mm.	Weight Kg. per km.	Resistance per km. at 20°C ohms.	Current rating for temperature rise of 55.5°C amps.
4/0	10.1600	81.0732	720.7	0.2175	278
3/0	9.4488	70.1202	623.4	0.2516	250
2/0	8.8392	61.3643	545.5	0.2877	226
1/0	8.2296	53.1921	472.9	0.3320	203
1	7.6200	45.6037	405.4	0.3875	181
2	7.0104	38.5990	343.2	0.4579	158
3	6.4008	32.1780	286.1	0.5495	139
4	5.8928	27.2730	242.4	0.6489	122
5	5.3848	22.7734	202.4	0.7770	107
6	4.8768	18.6792	166.06	0.9478	92
7	4.4704	15.6958	139.53	1.129	81
8	4.0640	12.9717	115.32	1.366	70
9	3.6576	10.5071	93.44	1.686	60
10	3.2512	8.3019	73.79	2.136	50

enter directly the following one, so that the same current flows through all of them, the elements are said to be connected in series; and the circuit is then known as a series circuit. A general series circuit is shown in Fig. 1.5, where

B = Source of supply, a battery.

S = Control-device, a switch.

F = Protective device, a fuse-wire.

A = Instrument or meter, an ammeter.

L = Power consuming device, a load-resistance.

W = Connecting wire.

Since every element of the circuit in Fig. 1.5 is a conductor and possesses resistance, the equivalent condition in the circuit is like some resistors of various magnitudes having been connected in series. A series circuit with resistors R_1, R_2, R_3 ..., etc. is shown in Fig. 1.6. If the resistances of the elements other than the resistors are neglected, and since the same current flows through all the resistors R_1, R_2, R_3..., etc., the total resistance (R) offered to the flow of current is the sum of all these resistances, giving

$$R = R_1 + R_2 + R_3 \ldots \quad (1.1).$$

When Ohm's Law is applied to the series circuit, as shown in Fig. 5, the voltage of the battery B is given by

$$E = I.R. = I\ (R_1 + R_2 + R_3 + R_4 + R_5)$$
$$= IR_1 + IR_2 + IR_3 + IR_4 + IR_5 \ldots (1.2).$$

If we denote the products IR_1, IR_2, IR_3....etc. by V_1, V_2, V_3.....etc, then

$$E = V_1 + V_2 + V_3 + V_4 + V_5 \ldots$$

This shows that Ohm's Law is applicable to the various parts of the series circuit also, namely, $V_1 = IR$, $V_2 = IR_2$, $V_3 = IR_3$....and so on ...(1.3).

The voltages IR_1, IR_2, IR_3, .. etc., are known as the voltage drops in the circuit. The voltage drop IR_1, or V_1 means that a p.d. of V_1 volts is necessary to force a current of I ampere through a resistance of R_1 ohms. In this way the total voltage necessary to force a current of I amperes in this series circuit will be the sum of all the voltage-drops IR_1, IR_2, IR_3 .... etc. Therefore, in general the p.d. of a voltage-source necessary to send a current through a series circuit is equal to the sum of the voltage-drops in the various parts of the series circuit caused by that current.

The rules of the series circuit may be summarised thus.

(i) The current in every part of the series circuit is the same.

(ii) The total resistance of the series circuit is given by the sum of the individual resistances of the various parts as in Equation (1.1).

(iii) The voltage-drops across the individual resistances in a series circuit are directly proportional to the magnitudes of those resistances, as in Equation (1.3).

(iv) The total applied voltage across a circuit with the resistors connected in series is equal to the sum of the voltage drops across the individual units, as in Equation (1.2).

Example:

A series circuit consisting of three resistors of values 25, 35, and 50 ohms respectively is connected across a battery. The current flowing through the circuit is measured by an ammeter, and is found to be 2 amps. Neglecting the

resistances of the battery, ammeter and the connecting wires, calculate·

(a) the voltage-drop across the individual resistors and

(b) the total applied voltage of the battery.

Solution·

(a) Since the resistances are in series, the same current of 2 amps flows through all the resistors So if the voltage drops across the resistors are denoted by V_{25}, V_{35} and V_{50}, then $V_{25}=2\times25=50$ volts Ans.; $V_{35}=2\times35=70$ volts Ans.; $V_{50}=2\times50=100$ volts Ans.

(b) The total applied voltage of the battery will be

$$E=V_{25}+V_{35}+V_{50}$$
$$=50+70+100=220 \text{ volts Ans.}$$

The applied voltage can also be found by combining the resistances, so that

$R=R_1+R_2+R_3=25+35+50=110$ ohms and $E=IR=2\times110=220$ volts Ans.

The voltage drops also can be found from the total applied voltage.

$$I=\frac{E}{R}=\frac{E}{R_1+R_2+R_3}$$

and $V_1=IR_1=\dfrac{E\times R_1}{R_1+R_2+R_3}$.

Similarly $V_2=IR_2=\dfrac{E\times R_2}{R_1+R_2+R_3}$

and $V_3=IR_3=\dfrac{E\times R_3}{R_1+R_2+R_3}$

so that,

$$V_{25}=\frac{220\times25}{110}=50 \text{ volts Ans.}$$

$$V_{35}=\frac{220\times35}{110}=70 \text{ volts Ans.}$$

$$V_{50}=\frac{220\times50}{110}=100 \text{ volts Ans.}$$

Note that, in general, if nothing is mentioned, the resistances of connecting wires and ammeters are always ignored in the calculations, as they are very small.

1-12. Parallel Circuit

When the various elements of a circuit are connected in such a way that points at one end of all elements are connected together to form one junction, and the points at the other end of the same elements are connected together to form another junction, and the voltage source is connected across the two junctions, the various elements are said to be connected "in parallel" Under this condition, the same voltage is applied to all the elements simultaneously.

Fig. 1.7 shows a circuit of four resistors R_1, R_2, R_3 and R_4 connected in parallel to one another. A, A_1, A_2, etc. are ammeters whose resistances are negligible as indicated in the case of series circuit The resistors R_1, R_2, R_3 and R_4 are joined together at the junctions a and b, and a voltage E has been applied across a b from a battery through a switch, so that each of the resistors R_1, R_2, R_3 and R_4 are having the voltage E across each of them. The current I from the battery B is divided into I_1, I_2, I_3 and I_4 in four branches at junction 'a' and again combining at the junction 'b'.

When Ohm's Law is applied to this parallel circuit, the voltage drop in each of the resistors will be equal to the applied voltage E. Therefore.

$$E=I_1R_1=I_2R_2=I_3R_3=I_4R_4$$

so that $I_1=\dfrac{E}{R_1}$; $I_2=\dfrac{E}{R_2}$; $I_3=\dfrac{E}{R_3}$;

$$I_4=\frac{E}{R_4}\ \ldots.(1.4).$$

Now, the total current supplied by the battery is:

$$I = I_1 + I_2 + I_3 + I_4$$
$$= \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} + \frac{E}{R_4}$$
$$= E\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}.$$

If the combined resistance offered by all the parallel resistances to the current I is R, then according to Ohm's Law,

$$E = IR, \text{ or } I = \frac{E}{R}$$

Therefore,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\text{or } R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}} \quad \ldots.(1.5).$$

So, the combined resistance of a group of resistors connected in parallel is equal to the reciprocal of the sum of reciprocals of the individual resistances of the resistors. This combined resistance is known as the equivalent resistance of the parallel circuit It is often necessary to replace the resistance of a parallel circuit by this equivalent resistance for the purpose of calculation, which means that if this resistance is connected across a voltage source of the same magnitude as that in the actual parallel circuit, the same total current would be drawn from the source.

The rules of the parallel circuit may be summarised thus:

(i) The same voltage is applied across all the parallel resistors simultaneously

(ii) The total current flowing from the voltage source to the entire group of resistors is equal to the sum of the currents in the individual branches

(iii) The individual currents in the resistors are inversely proportional to the magnitudes of the individual resistances of the resistors, as in Equation (1 4).

(iv) The equivalent resistance of the parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the resistors, as in Equation (1.5)

Example:

A parallel circuit consisting of three resistors of values 20, 30, and 60 ohms respectively is connected across a battery of voltage 120 volts. Calculate (a) the current flowing in the three branches and the total current from the battery and (b) the equivalent resistance of the circuit The battery-resistance may be neglected.

Solution:

(a) Since the same voltage of 120 volts acts across each of the resistors, the branch-currents are·

$$I_{20} = \frac{120}{20} = 6 \text{ amps. Ans ;}$$

$$I_{30} = \frac{120}{30} = 4 \text{ amps Ans ;}$$

$$\text{and } I_{60} = \frac{120}{60} = 2 \text{ amps. Ans.}$$

The total current $I = I_{10} + I_{20} + I_{40}$
$= 6 + 4 + 2 = 12$ amps. Ans.

(b) The equivalent resistance

$$R=\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$$

$$=\frac{1}{\frac{1}{20}+\frac{1}{30}+\frac{1}{60}}$$

$$=\frac{1}{\frac{3+2+1}{60}}=\frac{1}{\frac{6}{60}}$$

$$R=\frac{60}{6}=10 \text{ ohms. Ans.}$$

The total current can also be found from this by applying Ohm's Law,

$$I=\frac{E}{R}=\frac{120}{10}=12 \text{ amps. Ans.}$$

Example:

A hall in a large building has twenty-four 150 watt 120-volt lamps. They are connected in parallel. If the resistance of each lamp is 96 ohms, calculate

(a) the current through each lamp,

(b) the total current taken by all lamps,

(c) the equivalent resistance of all the lamps together.

Solution:

(a) By Ohm's Law, the current per lamp

$$I=\frac{120}{96}=1.25 \text{ amps. Ans.}$$

(b) The total current I_t for 24 lamps $=24\times1.25=30$ amps. Ans

(c) The equivalent resistance is

$$R_t=\frac{1}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4}\cdots},$$

where resistance of each lamp $r_1=r_2=r_3=r_4=r$ say.

$$\therefore\quad R_t=\frac{1}{\frac{24}{r}}=\frac{r}{24}$$

$$=\frac{96}{24}=4 \text{ ohms. Ans}$$

This result can also be obtained from (b), the equivalent resistance $R_t=R_{eq}$

$$=\frac{120 \text{ volts}}{30 \text{ amps.}}=4 \text{ ohms}$$

Also, the results of (b) can be obtained from (c), total current

$$I_t=\frac{120 \text{ volts}}{4 \text{ ohms}}=30 \text{ amps.}$$

From the results of the Example we conclude that the equivalent resistance R_{eq} of n number of equal resistances in parallel each of value R is given by

$$R_{eq}=\frac{R}{n}.$$

1-13. Series-parallel Circuit

In many cases resistors are connected in the combined manner of series and parallel connections with respect to the source of potential. As an example, we may consider the case of a D.C. generator supplying a load through a feeder line. In this case the load may consist of a number of resistors in parallel, and it is connected to the voltage source through the series resistances of the feeder line, as shown in Fig. 1.8(a). This may also be represented by the Fig. 1.8(b) where the three load resistors R_1, R_2, and R_3 carrying currents I_1, I_2 and I_3 respectively are replaced by an equivalent load resistor R_L having a current I in it. As was shown earlier in equation (1.5), the equivalent load-resistor R_L is given by

$$\frac{1}{R_L}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

and the total resistance across the generator voltage E is

$$R = R_f + R_L + R_f = 2\,R_f + R_L$$

and the total current $I = \frac{E}{R}$

$$= \frac{E}{2\,R_f + R_L}$$

If Ohm's Law is applied to Fig 1 8 (b), we have $E = IR_f + IR_L + IR_f$, so that the voltage across the load is

$$V_L = IR_L = E - 2\,IR_f.$$

Hence 2 IR_f is called the *voltage drop* in the feeder lines, the leading or positive line XA having a drop of IR_f volts and the return or negative line yB also IR_f volts.

1-14. Power and Energy

As we have seen already, an electric circuit is a path through which electrons are forced to flow because of the application of a p d. so that they can do work. Electric power is the rate at which this work is done This work is also called energy Therefore electric power is the rate at which electric energy is transformed or changed into some other forms of energy like light, heat, etc.

Let us take an instance to understand the meaning of power and energy. A man pulling a loaded cart from one place to another distant place in two hours has done some work. A horse pulling it across the same distance in fifteen minutes does the same work But since the horse has done the same work in a much shorter time, we say that the horse is more powerful than the man. Here the man and the horse have each spent the same amount of energy, but the man could spend the energy at a much slower rate than the horse.

As mentioned earlier, the unit of electric power is a watt, named after the inventor of the steam engine, James Watt, who first felt the need to define the rate of doing work. The unit of electrical energy is a watt-hour. A watt-hour represents an amount of work or energy, when energy has been spent at the rate of 1 watt for 1 hour, or ½ watt for 2 hours, or 2 watt for ½ hour and so on Therefore, the amount of energy in watt-hour is obtained by multiplying power in watts by time in hours In practice, a larger unit of energy, known as a Kilowatt-hour, is used. It is 1000 times a watt-hour, and is abbreviated as KWH Similarly, for power also, a larger unit called a Kilowatt is used very often, and this is 1000 times a watt.

A 60-watt electric lamp gives us a certain amount of light A 100-watt lamp will give us more light Although both the lamps are transforming electrical energy into light energy, the 100-watt lamp will do this at a faster rate than the 60-watt lamp, indicating that the former is more powerful than the latter.

In a circuit,

If P = power in watts,
E = Voltage in volts,
and I = current in amperes

$$\text{then } P = E \times I \text{ and } I = \frac{E}{R} \quad \ldots(1.6)$$

Also, we know from Ohm's Law that

$$E = IR \text{ and } I = \frac{E}{R}$$

Substituting these two relationships

in equation (1 6), we get two other expressions for the power P.

$$P = E\,I = IR.I = I^2R \qquad \ldots(1.7)$$

$$\text{and } P = E.I = E\,\frac{E}{R} = \frac{E^2}{R} \qquad \ldots(1.8)$$

The power in a circuit can be calculated by using any of the three equations (1 6), (1 7) and (1 8), depending on which two quantities out of the three are known

If t = time in hours,
and w = energy in watt-hours,
then $w = p \times t$

$$= EI\,t$$

$$\text{or } I^2Rt$$

$$\text{or } \frac{E^2}{R}t \qquad \ldots(1.9).$$

Example:

What is the wattage (power rating) of an electric toaster that takes 5 amperes current when plugged into a 220-volt socket outlet?

Solution:

Using equation (1.6)

$$P = E\,I = 220 \times 5 = 1100 \text{ watts. Ans}$$

or 1 1 Kilowatts (Kw) Ans.

Example:

The resistance of the heating element (nichromewire) of an electric heater is 40 ohms and uses 5 amperes when connected to the rated voltage source. What is the wattage of the element?

Solution:

Using equation)1.7)

$$P = I^2R = (5)^2 \times 40 = 25 \times 40$$

$$= 1000 \text{ watts. Ans}$$

or 1 Kw Ans

Example·

The resistance of the dash-light of a motor-car is 18 ohms, and is supplied from a 6-volt battery What will be the wattage of the bulb?

Solution·

Using equation (1.8)

$$P = \frac{E^2}{R} = \frac{(6)^2}{18} = \frac{36}{18} = 2 \text{ watts. Ans.}$$

Example.

An electric ironer uses 1100 watts when connected to a 220-volt supply. What current does it take and what is its resistance? If this ironer is used for 2 hours, how much energy will be consumed?

Solution·

Using equation (1.6).

$$I = \frac{P}{E} = \frac{1100}{220} = 5 \text{ amps. Ans.}$$

Using equation (1.7)

$$R = \frac{P}{I^2} = \frac{1100}{(5)^2} = \frac{1100}{25}$$

$$= 44 \text{ ohms. Ans}$$

Using equation (1.9)

$$w = Pt = 1100 \times 2 = 2200 \text{ watt-hours. Ans.}$$

or 2.2 KWH. Ans.

QUESTIONS AND EXERCISES

1 If a glow lamp takes a current of 0 3 ampere when connected across a 240-volt circuit, what will be its hot resistance? [Ans. 800 Ω]

2. State and explain Ohm's Law briefly. The heating element of an electric stove, suitable for use on a 220-volt supply, is found to have a resistance of 20 ohms. What current will the stove take when connected to 220-volt mains? [Ans 11 A.]

3. Show, with a circuit diagram, the grouping of 8 cells as (a) all in series, (b) in two parallel groups of 4 cells in series, and calculate the voltage and resistance between the

terminal in each case, assuming that each cell gives 1 2 volt, and has a resistance of 0 8 ohms.

[Ans. (a) 9 6V.; 6.4
(b) 4 8V; 1.6]

4 Name the units of resistance, e m f, current, and potential difference. Four batteries, each of two volts and kept in series, form the supply to three resistance coils, in series, each having a resistance of 50 ohms. Calculate the current in the circuit, and the potential difference between the ends of each resistance coil.

[Ans. 0.0533 A; 2.67V.]

5 Three resistances of 6 ohms, 9 ohms and 18 ohms respectively are connected in parallel, and this group of three resistances is placed in series with a single resistance of 3 ohms and a battery of 24 volts having negligible resistance

Find the total current taken from the battery, and the current passing through the 6-ohm resistance. What would be the values of these currents, if the battery has an internal resistance of 4 ohms? [Ans. 4A;2A and 2.4A; 1.2A]

6. A coil is wound with copper wire, 20 metres long and of square cross-section of 0.5 cm x 0.5 cm If the specific resistance of copper is 1.7 micro-ohms per cm cube, calculate the resistance of the coil.

[Ans. 0.0136]

7 Two exactly equal pieces of copper are drawn into wire: one into a 4 m long wire, and the other into an 8 m long wire. If the resistance of the shorter wire is 0.5 ohm, what would be the resistance of the longer wire?

[Ans. 1 415 Ω]

8 The resistance of a coil of wire at 20°C was seen to be 45.2 ohms. As the temperature increased to 60°C, the resistance increased to 46.00 ohms Calculate the temperature co-efficient, α of the wire

[Ans. 4.425×10^{-1} / °C]

9 A certain heating element is made of nichrome wire, which has a temperature co-efficient $\alpha_{20} = 0\ 0004$. If the coil has a resistance of 20 ohms at 20°C, what is the operating temperature when its resistance has increased to 20.2 ohms? [Ans 500°C]

10. Distinguish between Power and Energy, and state their respective electrical units. What is the wattage rating of an electric lamp, the filament of which has a resistance of 400 ohms, when the potential across its connecting terminal is 200 volts?

[Ans 100 W]

11. An electric motor operating on D.C takes 360 amperes at 230 volts and has an efficiency of 90%. How much power will it deliver?

[Ans. 74.5 Kwh]

12 When the electrical energy is sold at 5 paise per Kwh at a place, and the monthly bill comes to Rs. 3 75, calculate the electrical energy consumed in kilo-watt-hours

[Ans 75 Kwh]

13. Distinguish between conductors and insulators. Name a few conducting and insulating materials.

CHAPTER 2

Magnetism and Electromagnetics

A MAGNET is a piece of metal that attracts certain other metals This attraction is known as magnetism The earliest known magnet is the Lodestone, possessing the property of attracting iron particles naturally. This is a natural magnet. The word 'magnet' has come from its place of discovery, the town of Magnesia in Lydia, Asia Minor. This material has little practical value today except as a museum-piece or an object of laboratory curiosity, because of the insufficient force of attraction that it can produce in comparison with modern artificially-made permanent magnets. The three known elements that can be so magnetised are iron, nickel and cobalt. Iron is far superior to the other two elements in this respect But certain alloys of iron make even stronger magnets than pure, unalloyed iron.

All matter is made up of atoms Magnetism is produced by electrons as they revolve about the nucleus of an atom, as shown in Fig 2 1 In a non-magnetic metal, the electrons within the atoms rotate in disorderly patterned orbits, as shown in Fig 2.2(a) When the metal has been magnetised, the electrons within large groups of atoms get themselves reoriented, and this results in their moving in the same direction, as may be seen in Fig. 2.2(b). Under this condition, the magnetism of all the electrons gets added together and the metal becomes a magnet.

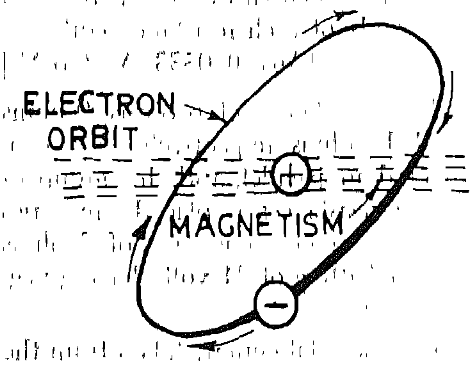


Fig. 2.1. An Atom with an Electron

2-1 Permanent Magnets

Magnets that exist naturally or are made artificially may be divided into two classes:

(1) *Permanent magnets*—A magnet that retains its magnetism for a long time, even after the withdrawal of [illegible] rce, is known as a

(ii) *Temporary magnets*—A magnet which loses its magnetism with the withdrawal of magnetizing force is known as a temporary magnet.

2-2. The Strength of a Permanent Magnet

The strength of a magnet depends on the number of electrons lined up and circling in the same direction. When the number of electrons is small, the strength of the magnet will also be small. A large number of electrons lined up and circling in the same direction will make a stronger magnet. When all the electrons in a magnet are lined up by magnetisation, the strength of the magnet can no longer be increased. Under this condition, the magnet is said to be *saturated*.

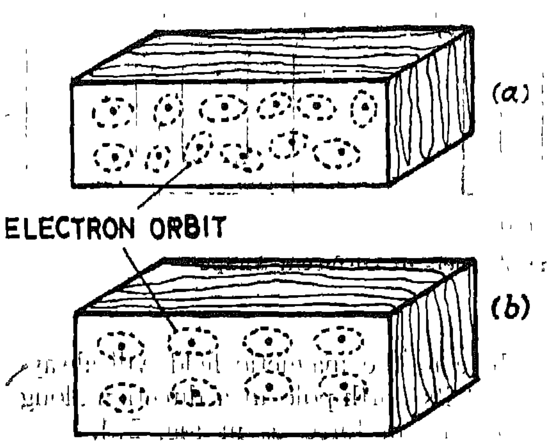


Fig. 2.2. Movement of Electrons, (a) when not Magnetised and, (b) when Magnetised

2-3. Magnetic Poles

If a magnet is suspended by means of a thread tied at its middle, one will see that it always remains in the north-south direction. The two ends of a magnet pointing towards north and south are known as the poles. The end pointing towards the north is known as the *north pole* and the one pointing towards the south is called the *south pole*.

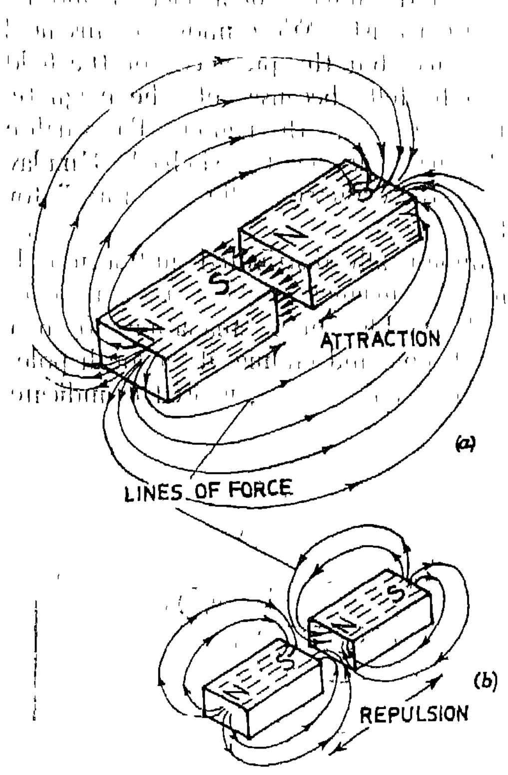


Fig. 2.3. Attraction and Repulsion between two Bar-magnets

When the north pole of one magnet is brought near the south pole of another, the magnets are found to attract each other, as shown in Fig. 2.3(a). When the north pole of one magnet is brought near the north pole of another, the magnets are found to repel each other, as shown in Fig. 2.3(b). This phenomenon is known as the *law of magnetic attraction and repulsion*. We may say in general that unlike magnetic poles attract, and like magnetic poles repel each other.

2-4. The Magnetic Field

The *magnetic* field or the field of force is the space around a magnet, in which the forces of attraction and repulsion exist. We cannot see this field of force, but the presence of the field can be felt because of the magnetic forces acting in the region To visualise the magnetic field, Michael Faraday used the expression "lines of force" for the first time, and pictured these as symmetrically distributed and surrounding the magnet. These are imaginary and invisible lines, emanating from a north pole and ending at a south pole. Another term, "flux", is used to indicate the magnetic lines of force in general. A small *compass needle*, which is nothing but a small magnet, will trace a path corresponding to a line of force when the needle is moved from a north pole to a south pole. A compass needle, when pivoted or suspended from its centre and left to itself, will always point in a north-south direction This fact proves that the earth itself is a sort of magnet. The end of the compass pointing in a north direction is called the north pole, and the other end pointing south, is called the south pole of the needle The magnetic field surrounding a Bar-magnet, a U-shaped-magnet, and an E-shaped-magnet is shown in Fig 2 4(a), (b) and (c) respectively One can reach the following conclusions after studying the sketches in Fig. 2 4·

(i) the magnetic fields surrounding the uniformly constructed magnets, as shown by the pattern of the lines of force, are always symmetrical, unless they are disturbed by the presence of another magnetic substance on the path;

(ii) a compass needle placed anywhere in the magnetic field will always point its north-pole in a direction along the lines of force, as in Fig. 2.4;

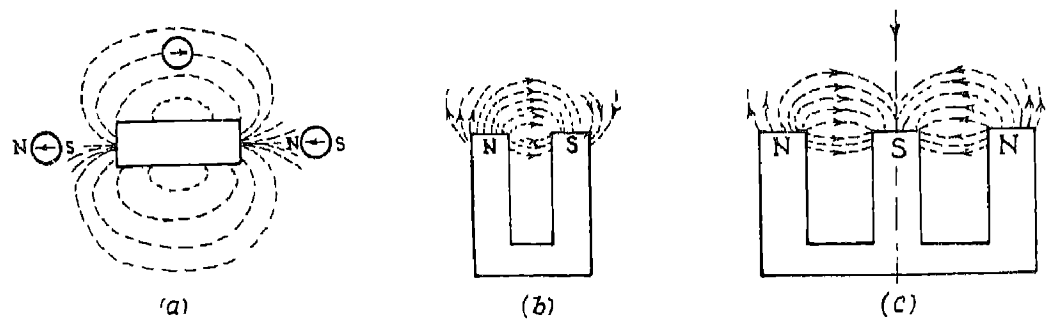


Fig. 2.4. Field Patterns of the Magnets of Different Shape

(iii) the lines of force have direction, and are always represented as leaving the north and entering the south pole; and

(iv) the greatest *field intensity*, i.e., the line of force per unit area, always occurs near the pole surfaces and decreases with increasing distances from the poles.

2-5. Magnetic and Non-magnetic Materials

The magnets attract some metals and do not attract others The metals which are attracted by a magnet are called *magnetic materials*. A magnet can be made out of these materials. Iron, steel, cobalt and nickel belong to this class of materials. The metals, that are not attracted by magnets, nor capable of being made into a magnet, are known as *non-magnetic materials* Copper, aluminium, gold, silver and lead belong to this class. Most of the non-metallic materials also belong to this category. Cloth, paper, glass, porcelain, plastic and rubber also are non-magnetic materials.

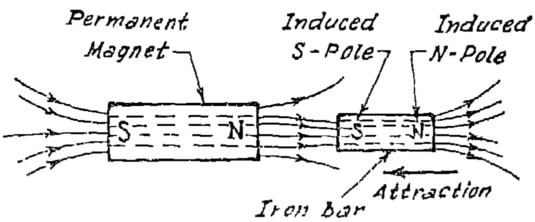


Fig. 2.5. Magnetisation by Induction

The strongest and the best permanent magnets can be made out of some metal alloys. The common alloys for this purpose are: (i) Alnico (aluminium, nickel, iron and cobalt); (ii) Vicalloy (vanadium, iron and cobalt); (iii) Permalloy (nickel and iron or cobalt-nickel and iron). Weaker Permanent Magnets can be made out of hard-tempered iron or steel. Temporary magnets are usually made of soft iron or nickel.

2-6. Making Permanent Magnets

Fig 2.4(a) shows the symmetrical magnetic field of a bar magnet. If a bar of iron is brought near the magnet, as shown in Fig 2.5, the lines of force shown in Fig. 2 4(a) change their path and are drawn towards the iron bar The reason for this is that iron is magnetically more conducting than air, and so can accommodate a greater number of lines of force. Usually this ability of iron is known as *permeability*. This concentration of flux makes the iron piece move towards the magnet Under this condition, i.e., under the action of the magnetic field of the permanent magnet, the atoms in the iron get themselves so reoriented that the electrons in it are lined up and circle in the same direction. So the iron bar is now magnetised and it develops the poles, as shown in Fig. 2.5.

This process of making a magnet is known as *magnetisation by induction*. In actual practice a magnet is made, using this principle of induction, by stroking the object to be magnetised over a permanent magnet The strokes must be made in one direction only, i.e., either from the north pole to the south pole, or from the south pole to the north pole. A magnet can also be made by placing the object near and parallel to the permanent magnet, as shown in Fig. 2.6. However, only a weak magnet can be produced by this method.

To make a strong permanent magnet, a device called "Magnetiser" (to be described later) is used. Most of the permanent magnets used in industry are made by using this apparatus A magnetiser has a U-shaped magnetic

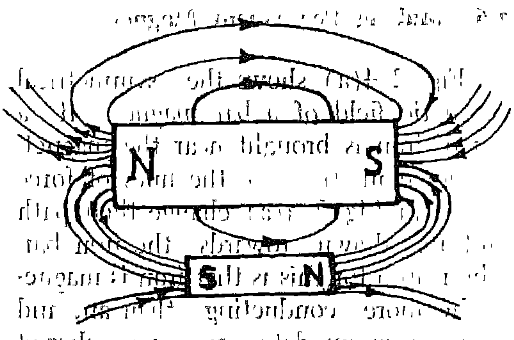


Fig. 2.6. Making a Magnet by Induction

core [illegible] both limbs. The [illegible] is kept on the [illegible] d, a direct current is passed through the coil thereby producing a strong magnetic field, as shown in Fig 2·7 When the current is switched off after a few seconds, it will be found that the object has become a magnet.

2-7. Uses of Permanent Magnet

(1) A [illegible] used to indica[illegible] permanent magnet (the needle) is [illegible] pivot point so that it [illegible]. The north pole of the needle will always point to the north direction of the earth, i.e, the needle will align itself in the north-south direction.

(2) [illegible] et chuck is used to [illegible] he table of a surface [illegible] er applications in the [illegible] some objects are screwdrivers, doors, knife-holders, potholders, charts, magnetic sweepers and some other devices.

(3) The principle of permanent magnetism is utilised in detecting cracks, scratches and other defects on the surface of metal castings and finished products in foundry, forging and machine shop work, by a process called "Magnaflux" By this process, the object to be tested is first of all magnetised and then, an oil containing small particles of iron is applied The particles are attracted to the surface of the object and form an irregular pattern of distribution around the defect This irregular pattern will ultimately lead to the location of the defect.

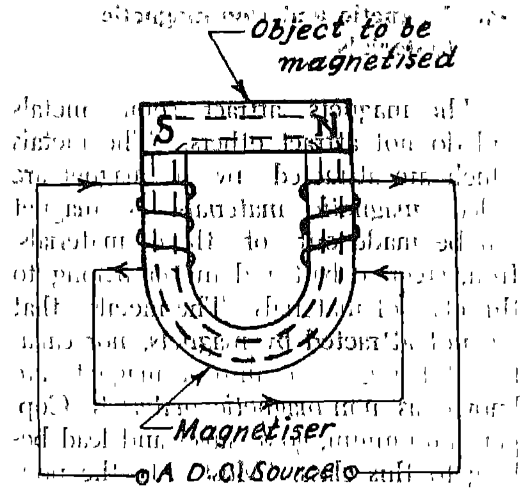


Fig. 2.7. Magnetisation by an Electro-magnet

2-8. Temporary Magnets

The magnets which do not retain their strength after the external magnetising forces are removed are called temporary magnets. These magnets are usually made of soft iron or an alloy of nickel and iron. They can be made with the help of permanent magnets by induction. They can also be made with electricity. These magnets retain the magnetic behaviour only as long as the magnetising force is present.

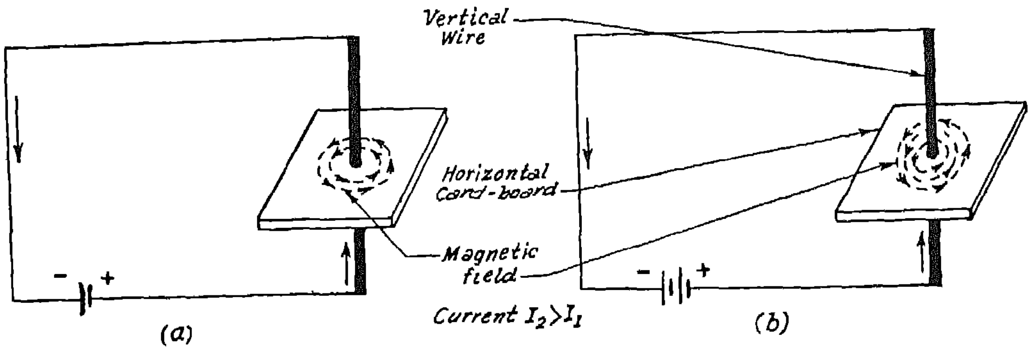


Fig. 2.8. Magnetic Field Produced by a Straight Current carrying Conductor

2-9. Magnetic Effects of Electric Current

Oersted, a Danish scientist, discovered that a magnetic field encircles a straight wire carrying current, as shown in Fig. 2.8(a) and (b). The direction of the magnetic field can be seen by placing a compass-needle on the horizontal card-board, and will be as shown in the figure for the direction of the current indicated. If the current-direction is reversed, the magnetic field direction will also be reversed The number of magnetic lines of force will increase with the increase of current through the conductor, as can be seen by comparing Figs 2.8(a) and (b). The idea of Oersted led to further discoveries concerning the magnetic effects of electricity. These effects are also produced by coils formed by bending wires into circular shapes and carrying current in them. The following important observations are made from an experiment conducted with a straight conductor, as shown in Fig. 2.8(a) and (b).

(i) The magnetic lines of force surround the straight conductor in concentric circles.

(ii) The flux density, i e, the lines of force per unit area, is inversely proportional to the distance from the centre of the conductor.

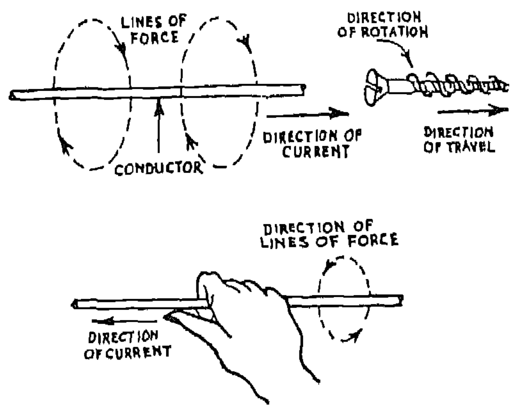


Fig. 2.9. Cork-screw Rule of Magnetisation

(iii) The direction of encircling lines of force may be determined by the *right-hand rule*, which states that if one grasps the straight conductor with the palm of the right hand so that the thumb points in the direction of current, the encircling fingers will indicate the direction of the lines of force around the conductor, as shown in Fig. 2.9. This rule is also known as the cork-screw rule,

because if the axial movement of a cork-screw represents the direction of current, then the clockwise rotation of the screw represents the direction of lines of force

2-10. The Solenoid

To produce appreciable and strong magnetic effects by a straight conductor, a very large current is necessary but this may cause many difficulties. If, however, the straight conductor is bent in the form of a coil, also called a *solenoid*, a smaller current would produce a stronger magnetic effect, as shown in Fig 2.10. It can be seen from this figure that the lines of force shown dotted are obtained from the same basic principle as for a straight conductor. Now these lines of force, from all the turns of the coil added together, give the resultant lines of force indicated by the full line in the figure The resultant magnetic field of the coil or solenoid shows that the flux emanates from the lower end and enters at the upper end, i.e., the lower end of the solenoid behaves like a north pole and the upper end like a south pole. Considering the facts stated above, a general rule about the polarity of a solenoid can be established thus: looking at the solenoid in the direction of its axis, if the current appears to flow in the anti-clockwise direction, this end would be a north pole; whereas if the direction of the current appears to be clockwise, then the end under consideration would be a south pole. A practical solenoid is a coil of insulated wire wound around a paper-tube or some other hollow tube of a length much greater than the diameter of coil.

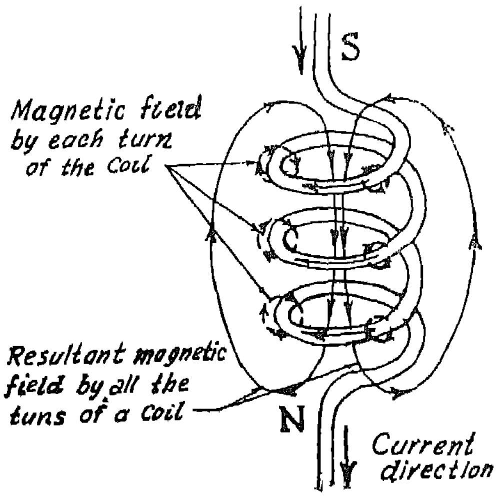


Fig. 2.10. Magnetic Field in a Solenoid

If a soft iron piece is placed near and along the centre-line of a solenoid, and current is passed through it, the soft iron, or "Plunger", as it is called, will be attracted inwards by the solenoid as it is magnetised by induction. If the plunger has a connecting mechanism, its movement can be utilised to control various devices, like switch, relay, valve, etc. A solenoid plunger device is shown in Fig. 2.11.

2-11. The Electro-magnet

An electro-magnet is made by having a solenoid wound on a soft iron core. Because of the high permeability of the iron, a much larger number of magnetic lines of force is established by the solenoid The use of soft iron core is necessary to have no magnetism left in it when the solenoid is de-energised. A solenoid with and without soft iron core is shown in Fig. 2.12

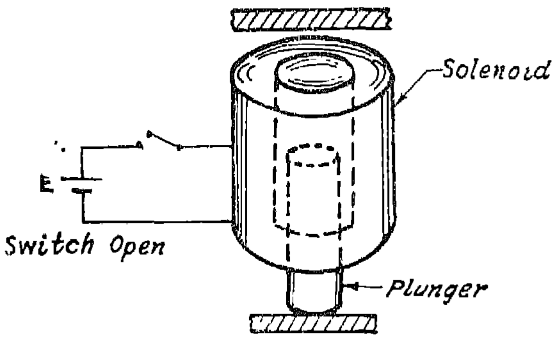


Fig. 2.11. **Movement of a Plunger in a Solenoid**

The strength of an electro-magnet depends mainly on

(i) the strength of the current in the coil,
(ii) the number of turns of the wire with which the coil is wound,
(iii) the material of the core, and
(iv) the size of the core and the general construction or design

For a given size and material of the core the strength of a given electro-magnet will depend on the product of current and the number of turns called *Ampere-turns* By keeping the ampere-turn the same, a magnet of a required strength can be obtained by many combinations of current and the number of turns

The polarity of an electro-magnet can be obtained by applying the same rule as for a solenoid

2 12. Effect of Wire-size on the Strength of Electro-magnet

The force exerted by the core of an electro-magnet depends on the number of ampere-turns. If the resistance of a coil of N turns is R ohms, and the voltage of the source to which the coil is connected is E volts, the number of ampere-turns will be $= \frac{E}{R} \times N$ In general, the supply voltage to which the coils of electro-magnets are connected is more or less constant, so that E will be assumed to be constant If we assume also that all the turns of wire of given size or cross-section have the same length, then the resistance of each turn of coil will be equal. Now, if we double the number of turns, keeping the size of wire the same, then the ampere-turns will be

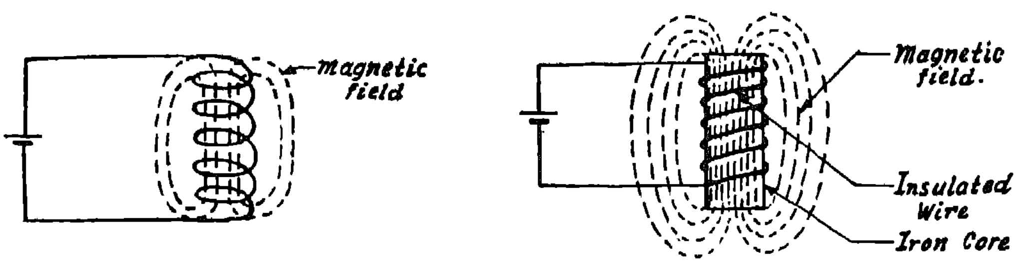


Fig. 2.12. A Solenoid with and without Magnetic Core

$$=\frac{E}{2R}\times 2N=\frac{E}{R}\times N,$$

which shows that changing the number of turns will not change the strength of the electro-magnet If, however, the size or cross-section of the wire is changed, say, to half of its previous value, then for the same material and length of each turn, the resistance per turn will become double (according to the law of resistivity as shown in the previous chapter). Therefore, for the same number of turns, N the ampere-turns, will become $\frac{E}{2R}\times N$, which is now half its previous value. This means that the strength of the electro-magnet will also come down to half its previous value. So we see that for a given number of turns of the same material and supply voltage, the number of ampere-turns will change almost in direct ratio to the cross-sectional area or size.

The power consumed by an electro-magnet will depend on the voltage of the source to which it is connected and the resistance of the coil. If the voltage is E and the resistance is R, then the power consumed, as shown in the previous chapter, will be equal to $\frac{E^2}{R}$.

Example:

The coil of an electro-magnet is wound with 1000 turns of wire and takes 200 watts from the supply when energised. Assuming that additional turns of the same size of wire will increase the resistance in direct proportion, how many turns will have to be added to the coil in order to reduce the power input to 100 watts at the same supply voltage?

Solution: Using the equation for power, $P=\frac{E^2}{R}$

$$P_1=200=\frac{E^2}{R_1}\text{ ; and } P_2=100=\frac{E^2}{R_2}$$

$$\frac{P_1}{P_2}=\frac{200}{100}=\frac{E^2}{R_1}\times\frac{R^2}{E^2}$$

$$\text{or }\frac{R^2}{R_1}=2\text{ , or } R_2=2R_1.$$

Therefore, the number of turns necessary is $2\times 1000=2000$,

and the increase in the number of turns

$2000-1000=1000$ Ans.

Example:

An electro-magnet is wound with a certain size of wire and the coil has a resistance of 80 ohms When connected to a supply of 120 volts it exerts a pull of 20 kg. If it is given that a 60% increase in the number of ampere-turns would increase the pull to 30 kg, determine (i) the relative size of the wire to be used in the new coil, (ii) the approximate resistance of the new coil, (iii) the approximate power input to the new coil. (Assume physical dimensions of both the coils to be the same)

Solution·

(i) Since for the same supply voltage the number of ampere-turns is practically proportional to the cross-sectional area of the wire, the new size of wire should be 60% larger or 1.6 times as large as the original wire.

Therefore, the relative size is 1 6 times larger. Ans.

(ii) Ampere-turns $AT_1=\frac{E}{R_1}\times N_1$;

$$AT_2=\frac{E}{R_2}\times N_2.$$

Since the space available for the coil is the same, an increase in the size of wire

will result in a decreased number of turns

Therefore, $N_2 = \frac{N_1}{1.6}$

So, $\frac{AT_2}{AT_1} = \frac{1.6}{1} = \frac{E}{R_2} \times \frac{N_1}{1.6} \times \frac{80}{E \times N_1}$

or $R_2 = \frac{80}{(1.6)^2} = 31.1$ ohms Ans.

(iii) Current $I_2 = \frac{120}{31.1} = 3.86$ amps

Power input $= 120 \times 3.86 = 464$ watts Ans.

The power taken by original magnet was

$$P_1 = \frac{(120)^2}{80} = \frac{120 \times 120}{80} = 180 \text{ watts.}$$

2-13. Magnetisation Characteristic of Iron and Steel

The strength of an electro-magnet, in terms of the number of lines of force it produces, will depend, among other things, on the number of ampere-turns developed by the exciting coil or coils For a given number of turns, therefore, the flux will depend upon the value of the current. The relationship between the flux-density (lines of force per unit area of cross-section) and the magnetising force in ampere-turns is known as the "magnetisation characteristics" An arrangement for determining this characteristic is shown in Fig 2.13. Starting with an unmagnetised core, if the current in the circuit is increased gradually from zero with the help of the rheostat, it will be noticed that the flux density (B) will increase in direct proportion with increase in ampere-turns (NI) up to a certain limit, as shown in Fig 2.14. This limit is reached at the point S. Beyond this point the flux-density increases at a slower and slower rate with further increase in the ampere-turns or magnetising force (H) The shape of the magnetisation characteristic will depend on the magnetic property of the material of the core These characteristics are very important for the makers of electro-magnets, electro-magnetic devices and machines

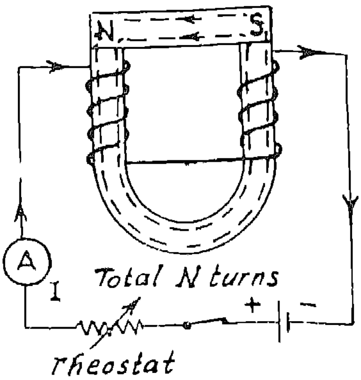


Fig. 2.13. Circuit Arrangement for Determining the Magnetisation Characteristic

In the curve of Fig 2.14 we can see that it is a straight line up to point S and then gradually bends rather sharply in the direction of X-axis up to point T beyond which the bend is inappreciable. From and above the zone ST of the characteristic, known as the **knee**, the iron is said to become saturated The degree of saturation is low at the knee, and is higher and higher with increasing values of ampere-turns beyond this point. Note carefully that saturation is a condition of the magnetic material when magnetised, and this indicates that the flux increases only slightly with further increase in the magnetising force Most of the electro-magnetic devices and machines work at a flux-density corresponding to a point just above the knee of the characteristic. The ratio B/H for any particular magnetic material gives its permeability.

2-14. Flux, M.M.F. and Reluctance

One of the characteristics of magnetic lines of force is that each line is a closed loop. For instance, in Fig. 2.15, the dotted line represents flux established in the core The complete closed path of the magnetic lines of force is referred to as a *magnetic circuit.*

In an electric circuit the current is due to the presence of an electromotive force By analogy we may say that in a magnetic circuit the magnetic flux is due to the presence of a *magnetomotive force* (M.M.F) caused by current flowing through the winding of one or more turns. The unit of M M.F is the ampere-turn. So in Fig. 2.15 the M M F acting in the magnetic circuit is NI ampere-turns. If the magnetic circuit is homogeneous and of uniform cross-sectional area, the M.M.F. per metre length of the magnetic circuit will be called the *magnetising force* or *magnetic field strength,* and will be represented by the symbol H. Referring to Fig. 2.15,

$$H=\frac{NI}{L}\text{ ampere turn/ meter}$$

The magnetising force (H) and the flux-density (B) are related by the absolute permeability (μ), so that $B=\mu H$. If the area, through which the flux is passing, is denoted by A, then flux

$$\phi=BA=\mu AH.$$

Substituting the value of H in terms of ampere-turns and length, we obtain for flux the expression

$$\phi=\frac{NI}{\frac{L}{\mu A}}\text{ or flux}=\frac{\text{M.M.F.}}{\text{Reluctance}},$$

where the flux ϕ is in webers, I in amperes, L in metres, A in square metres, N the number of turns and μ the absolute permeability

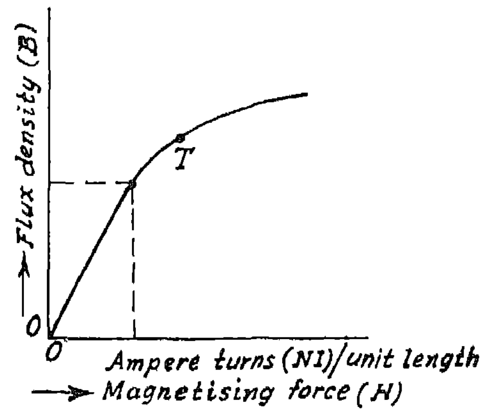


Fig. 2.14. The Magnetisation Characteristic of a Magnetic Material

We can see from the above that this expression has a similarity with the one in electric circuit, i.e.,

$$\text{current}=\frac{\text{E.M.F.}}{\text{Resistance}}$$

so that the flux, M M.F. and reluctance in the magnetic circuit are analogous to current, E M.F., and resistance in the electric circuit.

The reluctance $\frac{L}{\mu A}$ is expressed in ampere-turns/weber. The absolute permeability $\mu=4\pi\times10^{-7}\times\mu r$ where μr is the relative permeability of the medium in which the flux is produced. μr for air$=1$ and for iron and steel this may be several hundreds. Permeability is not constant when the iron is saturated because the ratio B/H varies with saturation as may be seen from Fig. 2.14

Calculations for series, parallel and series-parallel magnetic circuits can be done on the same principle as for electric circuits.

2-15. Pull Exerted by Electro-magnet

The pull exerted by an electro-magnet is given by (Fig 2.16)

$$P = \frac{B^2 A}{8\pi \times 10^{-7}} \text{ newtons,}$$

where, B = flux-density in webers/sq. metre
A = cross-sectional area in square metres
P = pull in newtons.

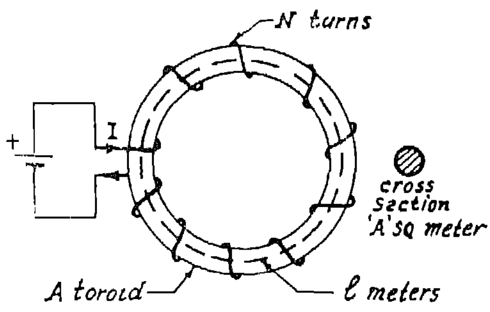


Fig. 2.15. A Toroid

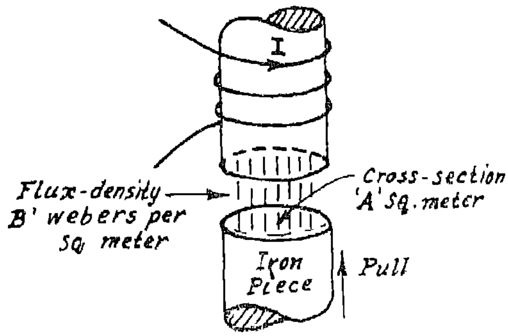


Fig. 2.16. Force of Attraction by an Electro-magnet

2-16 Force Between Two Parallel Conductors Carrying Current

It has been found by experiment that two parallel conductors carrying current in them experience a force acting between them. Whether the force is attractive or repulsive depends on the relative direction of current in them In Fig. 2.17(a), we see two parallel conductors, A and B, placed apart at distance 'd', carrying equal current I in the same direction The magnetic field or the lines of force established by each conductor is shown in Fig 2 17(b) and the resultant magnetic field in Fig. 2.17(c) Looking at Fig. 2 17(b) we can see that the lines of force due to conductors A and B are opposing one another in the space in between the conductor, and helping one another outside the zone so that the resultant lines of force would tend to encircle both the conductors As the lines of force always follow the path of minimum reluctance (since current follows the path of minimum resistance), they tend to bring the conductors closer and closer; because only by this action can the length of the path of lines of force and hence the reluctance be reduced. This means that the conductors are attracted to each other. So, we can deduce a general rule from this, namely, that *parallel conductors carrying current in the same direction are attracted to each other.*

In Fig. 2.18(a) are shown two conductors carrying current in opposite directions. Fig 2.18(b) shows the magnetic field produced by them. We see here that in the space in between the conductors the lines of force due to A and B help one another resulting in their being concentrated Because of this, the lines of force tend to push the conductors apart to get more space for a more even distribution of them. This means that there will be a force of repulsion between the conductors. So we can infer another general rule, that *parallel conductors carrying current in the opposite directions are repelled by each other.*

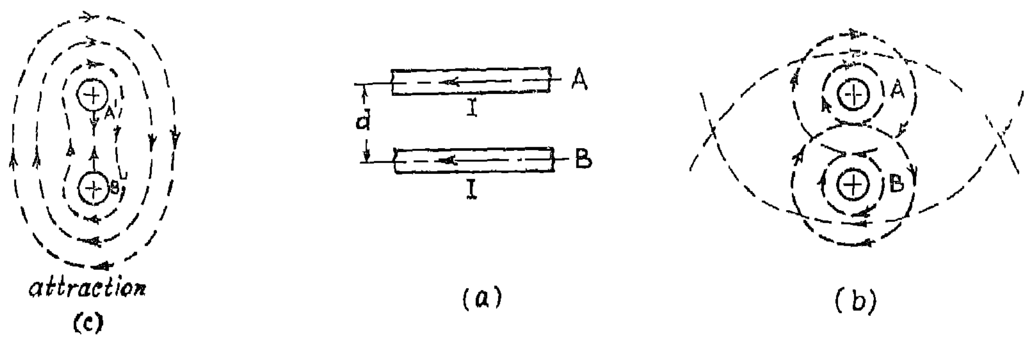


Fig. 2.17. Force of Attraction between Current-carrying Parallel Conductors

The force per metre length of conductor is given by an expression:

$$F = 2 \times 10^{-7} \frac{I_1 \times I_2}{d} \text{ newtons,}$$

where I_1 and I_2 are the currents in the two conductors respectively in amperes, and d is the distance in metres that separates the two conductors.

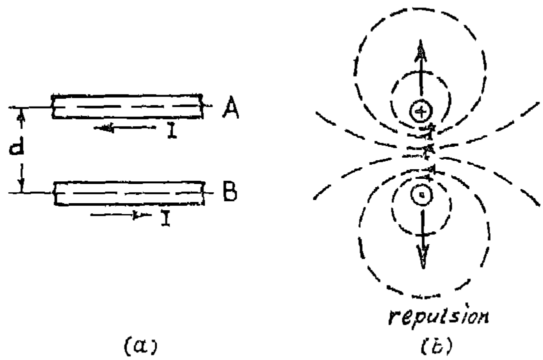
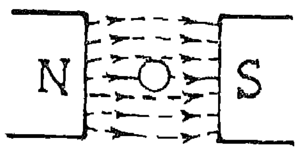


Fig. 2.18. Force of Repulsion between Current-carrying Parallel Conductors

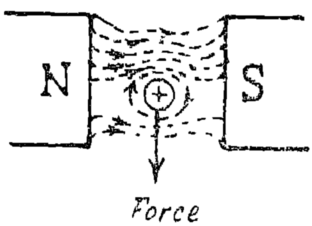
2-17 Conductor Carrying Current in a Magnetic Field

We saw earlier that the direction of magnetic field can be determined by a compass-needle which is nothing but a small magnet. If a compass-needle is placed near a current-carrying conductor, the needle will be deflected in the appropriate direction. This deflection means that the small magnet has experienced a force. This force can also be felt in the current-carrying conductor, if it is free to move and if the small magnet is held stationary. This is explained by Newton's Third Law of Motion, which states that every action has an equal and opposite reaction. This action is nothing but the interaction of the two magnetic fields—one by the current-carrying conductor and the other by the compass-needle. We can study the direction of this mutual force by considering Figs. 2.19(a) and (b). In Fig. (a) we consider a conductor carrying no current and placed in the main magnetic field produced by poles N and S with its axis at right angles to the field. The field distribution is seen to be uniform. In Fig. (b) the conductor is carrying a current in a direction of "going into the paper." By applying the right-hand or cork-screw rule, the direction of lines of force around the conductor, due to the current in it, will be clock-wise. This means that the flux due to the conductor will help that of the main field at the top and oppose it at the bottom of the conductor. This will result in the crowding of lines of force at the top and thinning of them at

the bottom of the conductor, so that the lines of force tending to straighten out at the top will push the conductor in a downward direction. We can observe an important rule working in this phenomenon, that is, *the magnetic field, the direction of current and the direction of force exerted on the conductor are all mutually at right angles to one another*



(a)



(b)

Fig. 2.19. A Current-carrying Conductor in a Magnetic Field

If the direction of current is reversed, the field produced by the conductor will now become anti-clockwise, resulting in a crowding of flux at the bottom of the conductor and hence a force pushing the conductor upwards, i.e., with the reversal of current, the direction of the force will also reverse if the direction of the main field remains the same. The same result will be obtained if the main field is reversed without reversing the current. If the current and the main field are both reversed, the direction of force acting on the conductor will remain the same

It is evident from Fig. 2 19(b) that as the current increases, the distortion produced also increases resulting in higher concentration of lines of force on one side of the conductor; and this consequently leads to a larger force Similarly, if the main field strength is increased it will produce a larger number of lines of force; and for a given current, the number of lines on one side will increase, resulting in an increased force. Also, the total force on the conductor will depend on the portion of its length, that is, in the main magnetic field This is so because the portion outside the main field may carry current and have its own magnetic field, but unless there is another field there can be no interaction, no field distortion and hence no force

In general it is true that the force on a conductor carrying current in a magnetic field will be proportional to the product of flux-density due to the main field (B), the current magnitude in the conductor (I), and the length of the conductor within the main field, also known as the "active length" (l) This force (F) can be written as

$$F = BIl \text{ newtons}$$

where, B = the flux density in webers/sq. metre

I = current in amperes

l = length in metres

The weber is a large unit, and either the *milliweber* (mWb) or the *microweber* (Wb) is often more convenient to apply, where,

1 milliweber = 10^{-3} weber

and 1 microweber = 10^{-6} weber.

2-18. Electromagnetic Induction

The principle of obtaining electric current with the help of magnetic flux, discovered by Michael Faraday in 1831, is known as the *electro-magnetic induction* He wound two coils A and B on

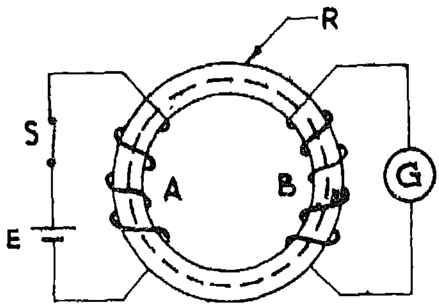


Fig. 2.20. **Electromagnetic Induction in a Coil Placed on the Magnetic Circuit of another Coil**

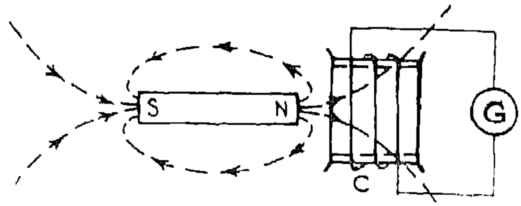


Fig. 2.21. Electromagnetic Induction in a Coil due to the Movement of a Magnet

an iron ring R, as shown in Fig. 2.20, and observed that as soon as the switch S was closed, a deflection in the galvanometer G was obtained. When the switch was opened, there was again a deflection of the galvanometre but in the reverse direction. He also noticed that when a permanent magnet SN was moved relative to the coil C, as shown in Fig. 2.21, the galvanometre showed some deflection. The deflection was in one direction when the magnet was moved into the coil, and in the opposite direction when it was taken out of the coil. It was also noticed that in both cases the deflection increased when the magnet was moved quicker.

This experiment proved that electricity can be induced in a conductor by the movement of a magnetic field relative to the conductor; it also showed that the magnitude of the current produced depended on the rate of change of this relative motion.

We see from Fig. 2.21 that the galvanometer circuit is a closed loop. To make a current flow in this loop an e.m.f. is necessary. And this e.m.f. is caused by the movement of the magnet relative to coil. This magnet has a flux which cuts or *links* the conductor of the coil. So, when the magnet is moved, the flux of the magnet cuts or links the coil at a rate determined by the rate of the change of position of the magnet. Hence, when there is a relative motion between a conductor and a magnetic field, an e.m.f. is induced in the conductor. The magnitude of this e.m.f. is determined by the rate of change of flux cutting or linking the coil.

2-19. Direction of Induced E.M.F.

There are two methods of determining the direction of the e.m.f. induced or generated in a conductor due to a magnetic field:

(1) Fleming's Right-hand Rule, and
(2) Lenz's Law.

Fleming's Right-hand Rule states that *if the first finger of the right hand be pointed in the direction of the magnetic*

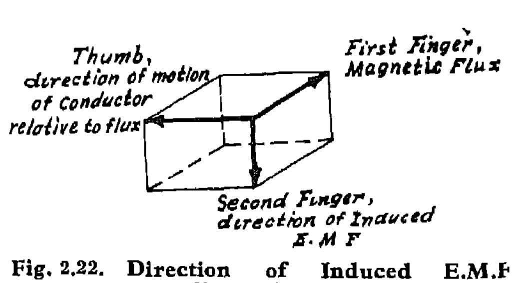


Fig. 2.22. **Direction of Induced E.M.F. according to Fleming's Right-hand Rule**

flux, as shown in Fig 2.22, and if the thumb be pointed in the direction of motion of the conductor, relative to the direction of the magnetic field, then the middle finger will point in the direction of the induced e m f. when these three fingers are held at right angle with respect to one another

(One should try this many times with the right hand placing the fingers, as shown in Fig 2.22, to get used to the rule.)

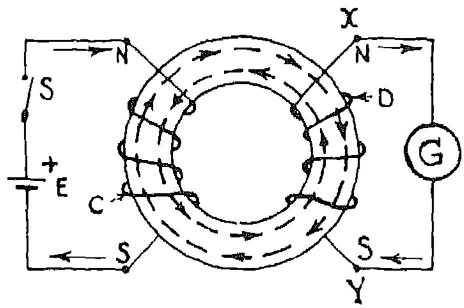


Fig. 2.23. Direction of Induced Current by Lenz's Law

The Lenz's Law states that *the direction of the induced e m.f. is always such that it tends to set up a current whose effect is always such as to oppose the cause which is producing it* The effect of current may be such as to oppose the motion or the change of flux responsible for inducing the e m f

Let us consider the application of Lenz's Law for determining the direction of induced e.m.f. in coil D of Fig. 2 23 As soon as the switch S is closed, a current will flow from the battery E to the coil C in the direction shown by arrow. The coil C is wound in such a way that, owing to this current, the upper end of the coil would be a north pole, and the lower end, a south pole resulting in a clockwise directed flux in the core. Now this flux, which corresponds to the ampere-turns in the coil when current increases in the coil from its zero to the steady state value, tends to establish itself in a very short time. As this flux tends to grow, it links the coil D and an e.m.f. is induced in it, the magnitude depending on the rate of the change of flux Since the circuit of coil D is closed, this induced e m f. would tend to circulate a current in it. According to Lenz's Law, this current must oppose the cause which produced it. The cause in this case is flux due to coil C. To oppose this flux, an opposing flux must be produced by coil D, and this can be achieved only if the upper end of this coil becomes a north pole and the lower end a south pole due to the induced current in it. To produce this polarity the current must flow in coil D in the direction XGY, as shown in the figure, which is also the direction of the e.m.f. induced

Next, let us consider the application of Lenz's Law for a conductor moving in a magnetic field as shown in Fig. 2.24 (a). The conductor has been placed in a mutually right-angled direction with respect to the magnetic field and the direction of motion. When this conductor moves in a downward direction, a current will flow in the closed circuit of the conductor due to an e.m.f. induced in it According to Lenz's Law, the effect of this current must oppose the cause which is producing it. The cause of this current is the induced e.m.f. which, in turn, has been produced by the

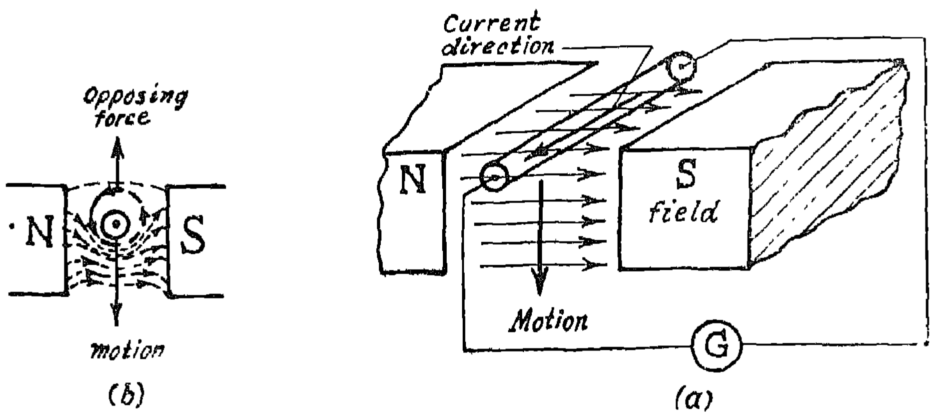


Fig. 2.24. Induced E.M.F. in a Straight Conductor Moving in a Magnetic Field

downward motion of the conductor So, the induced current must flow in such a direction that it must, interacting with the flux of the mainfield, produce a force in the conductor, so as to try to move it in an upward direction. This can be achieved only if the current in the conductor flows in the direction shown in Fig 2 24(b), i e, the resultant lines of force must be such as to cause a crowding of flux at the bottom of the conductor. This direction of current is also the direction of the induced e.m.f in the conductor.

It is important to understand these principles carefully, as these will be necessary to understand the principles of electro-magnetic machines discussed in the next chapter.

2-20. Uses of Electro-magnets

The electro-magnets are especially suitable for application in various kinds of electrical devices and equipments, because (i) their strength can be conveniently controlled by controlling the current and the air-gap, and (ii) they can be made in very large sizes and of considerable strength. Permanent magnets do not have these advantages

2-21 Bells and Buzzers

These belong to the class of vibrating type devices. Horns, flash signs, signal turning lights, electric shavers, etc, fall in this class

Fig 2.25 shows the various parts of an electric bell Before the switch is put on, the contact strip is held against the contact point by the tension of spring, as in fig 2.25(a). This permits current to pass through the coil of the electro-magnet when the voltage source is connected to the bell through a switch. The electro-magnet gets magnetised immediately, and attracts the armature (the moving part) to the position shown in Fig. 2.25(b) This produces a break in the electric circuit by removing the contact strip from the contact point This break

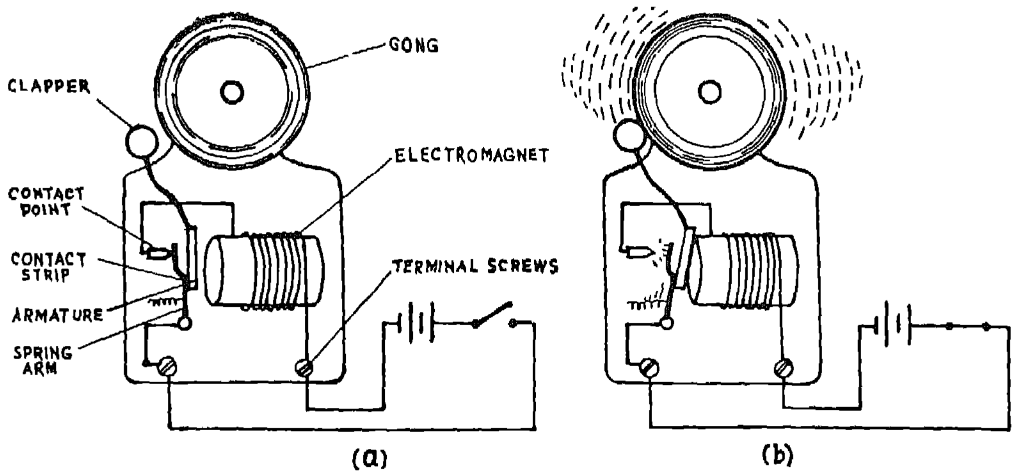


Fig. 2.25 Working Principle of an Electric Bell

stops the current flow in the coil and the magnet is de-energised. The electro-magnet loses its strength and the armature is brought back to the original position by the spring, bringing the contact strip into touch with the contact point. Then the whole thing will repeat itself over and over again so long as the voltage source remains connected to the bell Usually a hammer is attached to the armature which strikes a gong when attracted by the electro-magnet. This striking goes on intermittently, and so the bell rings. In a buzzer, the hammer and the gong are not present. The armature itself strikes the core of the electro-magnet, and thus produces a buzzing sound.

2-22. Relays

A relay is a device in which a switch is operated by an electro-magnet Fig. 2.26 shows a simple relay. When the electro-magnet is energised, the armature is attracted and makes contact between two contact points, thus closing a circuit. A relay may also disconnect a circuit on

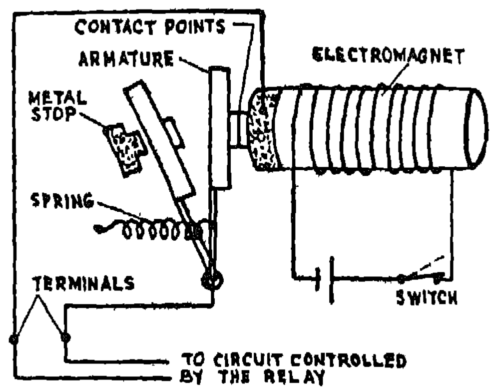


Fig. 2.26. Working Principle of an Electro-magnetic Relay

the same principle, i.e. the arrangement of the contactors would be such that the relay, when energised, will break a circuit. The use of relay makes it possible to control a circuit from a distant place. The relay also makes it possible to control a circuit carrying larger current by using very small current in an electro-magnet Relays are used in various types of automatic and control devices, in power stations, sub-stations, etc.

2-23 Inductance

In Chapter 1 we have seen that the voltage and current in a circuit are related by Ohm's Law. A current I amps would be established almost instantly in a resistor R ohms when a battery of E volts is switched on to it. But if the same resistor R is made by a piece of wire in the form of a coil wound round a magnetic core, it would take much longer time to establish the same current of I amps with the same battery voltage of E volts. When the battery is switched off the current will die down to zero immediately for a pure resistor, but will take some time in the latter case of the same resistor in the form of a coil. This phenomenon is caused by the e.m.f. of *self-induction*. A current flowing through the coil will produce a magnetic field which is linking it. When this current tries to change its value, the magnetic flux linking the coil will change simultaneously. The rate of change of this field will be determined by that of the current. This rate of change of flux linking the coil will produce the e.m.f. of *self-induction*. When Lenz's Law is applied to this case, the direction of this induced e.m.f. may be seen to be such as to oppose the flow of the current; so that the induced e.m.f. must act in the direction opposite to that of the applied voltage of the battery. As the current is gradually established, the rate of its change decreases, and ultimately, after a very short interval, the current becomes stationary.

The property of any circuit that opposes a change in the value of the current is known as *self-inductance*, or simply *inductance*. Inductance is responsible for causing a delay in the current attaining its full value. Under such conditions the current is said to *lag* behind the voltage. The greater the inductance, the greater are the delay and the lag.

The inductance of a circuit is equal to the self-induced e.m.f. in volts, set up in it when the current it carries varies at the rate of one ampere per second. The units of inductance is the *henry*. Thus, if the inductance of a circuit is 0.5 henry, and the current in it changes from 10 amps to zero in 0.5 seconds, the rate of change of the current is 20 amps per second and the self-induced e.m.f. tending to oppose the decrease of current will be 20 amps per second $\times$ 0.5 henry = 10 volts.

QUESTIONS AND EXERCISES

1. Explain the following terms:
   (a) Magnetic poles, (b) magnetic field; and (c) magnetic lines of force.
2. What is a permanent magnet and how is it made? Give some uses of permanent magnets.
3. Explain by means of a simple experiment, how you will show the magnetic effects of electric current.
4. What is the "cork-screw" rule? What does this rule indicate?
5. What is a solenoid? How will you determine the polarity of a solenoid?
6. What is an electro-magnet and on what factors does its strength depend?

7 Explain how the size of wire of the exciting coil of an electro-magnet will affect its strength.

8. What advantages does an electro-magnet have over a permanent magnet?

9. State the rule for determining the polarity of an electro-magnet.

10. A U-shaped electro-magnet has two similar coils of 200 turns each. They are connected in series so as to set up 2000 ampere-turns. Calculate: (a) the current in the coils, and (b) the resistance of each coil, if the supply voltage is 20 V D C.

[Ans 5A, 2Ω each]

11 Explain the terms (a) magnetic flux, (b) magneto-motive force and (c) reluctance in a magnetic circuit How are they related to one another?

12 Explain the magnetisation characteristic of a magnetic material. What do you mean by "saturation" of a magnetic circuit?

13. The mean length of a simple magnetic circuit is 50cm and the cross-sectional area through which the flux is produced is 5 sq cm., the relative permeability of the magnetic material being 800 If the exciting coil has 200 turns, carrying a current of 0.5 ampere in each turn, what is the value of the flux in webers produced in the magnetic core?

[Ans: 1.05×10^{-4} weber]

14 What will be the pull exerted by an electro-magnet of 50 sq. cm area and having a flux-density of 0 02 weber per sq. cm.?

[Ans: 0.08 Kg. weight]

15 Explain what happens when two parallel wires carry current in (i) the same direction, and (ii) two opposite directions

16 State the factors which govern the force exerted on a current-carrying conductor placed in a magnetic field

17. What do you understand by the term "electro-magnetic induction"? What factors determine the magnitude of the induced voltage?

18. Explain two methods of determining the direction or polarity of induced e.m.f.

19 A conductor, forming a closed circuit, is moved across a magnetic field. Determine the direction of current by applying Lenz's Law.

20. Explain, with a sketch, the principle on which an electric bell operates.

21. What is meant by the self-inductance of a coil? How does it affect the current flow in the coil?

CHAPTER 3

Effects of Electric Current and Electrical Machines

WE saw in Chapter 2 how eletric current produces and affects magnetism in various ways Since the initial experiments carried out in 1820 by Oersted who noticed a deflection of the magnetic compass-needle placed near a current-carrying conductor, "electromagnetism" has developed tremendously

3-1. Effects of Electric Current

The *heating-effects* of electricity were observed in the very early stages of development and understanding of the electrical phenomenon. Let us consider a common example of the heating-effect of electricity. An electric bulb or lamp has a thin wire, called filament, inside it. When it is switched on, the bulb glows Now, if the glass-surface of the bulb is touched, one can feel the heat. The reason for this higher temperature of the bulb is that the filament becomes heated when electric current passes through it, and it is heated so much that it gives out light So, when electric current passes through a conductor, its temperature increases to higher values above the ambient or surrounding temperature. The heating process depends on several factors, the most important of which are (i) the magnitude of the current, (ii) the resistance of the current-carrying conductor, (iii) the duration of the current flow, (iv) the kind and physical size of the heat-absorbing body and (v) the temperature, density and displacement of the surrounding medium. The effects of these factors can be illustrated by considering the case of an "Immersion-Heater". It is made of wire of high resistance in the shape of a coil, which can be immersed in a bucket or kettle of water or any other substance. When this heater is switched on to the supply (source of potential) it will heat up the water The rate of heating will increase with the increase of current through the heater and decrease with the decrease of current. Similarly, there will be a higher rate of heating when the resistance of the heater wire is increased without changing the current. The longer the duration of the current flow, the more will be the heat produced. The larger the surface area of the heater-wire the better will be the heat-dissipating capacity and better will be the rate of heating The less the temperature of the water, and the higher the heat conductivity of the water, the quicker will be the rate at which the water gets heated. In many devices and equipment this heat is purposely produced and uti-

lized But, in most of the electrical equipments, the heat produced by the current is undesirable, and elaborate and expensive arrangements are necessary to dissipate the heat and keep the temperature of the equipment concerned within safe limits

The *chemical effects* of electricity can be observed in certain kinds of liquids through which an electric current is passed The passage of current is accompanied by a chemical change called *electrolysis*. These liquids, called *electrolytes*, are chemical compounds or solutions of compounds.

When copper sulphate ($CuSO_4$) is in solution, each molecule of $CuSO_4$ dissociates into the positive ion Cu^{++} and negative ion SO_4 having positive and negative charges respectively When two electrodes, called *anode* and *cathode* are connected to the positive and negative terminals of a source of current (say, a battery), the positive ions will be attracted towards the cathode and the negative ions towards the anode This movement of ions constitutes the electric current in the electrolyte The Cu^{++} ion gives up its charge to the cathode and becomes an atom of copper. This copper is deposited as a film or layer over the cathode surface which means that the cathode is "copper-plated". The SO_4^{--} ion gives up its charge to the anode and becomes an SO_4 radical, which may combine with the metal of the anode to form a salt, or with hydrogen of water (H_2O) to form sulphuric acid (H_2SO_4), liberating oxygen of water.

From the nature of electrolysis of $CuSO_4$ it is clear that the mass or amount of copper deposited on the cathode will depend on the number of atoms Since each atom is responsible for carrying a definite number of charges, the mass deposited will also be proportional to the number of charges But the number of charges which enter the cathode is a measure of the quantity of electricity in coulombs. From this fact comes Faraday's first law of electrolysis stating that *the mass* (m)- *liberated is proportional to the quantity of electricity*(Q).

If a steady current of I amperes flows for t seconds, then $Q = It$

$$\therefore \; = m \propto Q$$

$$\text{or} \; = m \propto It$$

which may be expressed as $m = z$ It; where z is a constant and depends on the kind of substance deposited. This constant is called the *electro-chemical equivalent* of the substance, and can be expressed in terms of the electro-chemical equivalent of hydrogen (Z_H) thus

$$Z = Z_H \times \frac{\text{Atomic weight of element}}{\text{Atomic weight of hydrogen}} \times \frac{1}{\text{Valency}}.$$

From the above mentioned considerations, we get Faraday's second law of

electrolysis which states that *the masses of elements liberated by the same quantity of electricity are proportional to their chemical equivalents*

The principle of electrolysis can be used for the measurement of current, since the mass deposited is proportional to the current flowing for a given time. We have seen that

$$m = z\,It$$

$$\text{or } I = \frac{m}{zt}$$

so that if m, z and t are known I can be calculated When m is in gm, z is in gm per coulomb, and t is in sec., I is obtained in amp The apparatus which measures current by this method is called *Voltameter*

In a *silver voltameter*, pure silver plates are used as electrodes (anode and cathode), and silver nitrate ($AgNO_3$) is used as the electrolyte The measurement of current by the silver voltameter is so accurate that the 'International Ampere' has been defined on this basis The International Ampere has been defined as that value of unvarying current which, when passed through a solution in water of silver nitrate, according to standard specifications, deposits silver at the rate of 0 001118 gm per second

Other applications of the chemical effects of electricity are in electroplating, electro-refining, the production of oxygen, hydrogen, and chlorine gases, and the manufacture of metallic sodium, potassium, and caustic soda.

3-2. Primary and Secondary Cells

An *electric cell* changes chemical energy into electrical energy. This device produces e.m f. or voltage on account of the chemical action between certain substances For this reason an electric cell is also known as a *voltaic cell*. There are two main groups of electric cells, namely, the *primary cells* and the *secondary cells*

3-3. Primary Cells

Primary cells are of two types, namely, the wet-type and the dry-type

Wet-type· A simple copper-zinc cell shown in Fig. 3.1 is an example of wet-type primary cell This cell is not used for practical work, because of its unsatisfactory performance. But it is quite useful for demonstrating the basic action of any cell.

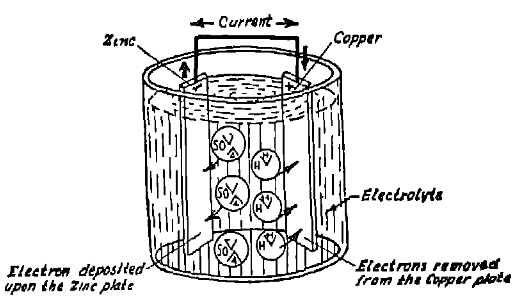


Fig. 3.1. A Simple Copper-Zinc Cell

The copper-zinc cell is made by placing strips of copper and zinc into a solution containing 20 parts of water and 1 part of sulphuric acid. This solution is called the electrolyte of the cell.

Wet cells have liquid electrolytes The sulphuric acid dissociates into positively charged hydrogen (H) ions and negatively charged sulphate (SO_4) ions.

The hydrogen ions are attracted by the copper The chemical action which takes place between these ions and copper removes electrons from the copper giving the copper a positive charge. The sulphate ions are attracted by the zinc. These ions form zinc-sulphate by combining with zinc-atoms This chemical action causes electrons to be deposited upon the zinc giving the zinc a negative charge. These two chemical actions produce an e.m.f. of approximately 1 volt between the copper and the zinc electrodes These two metals of the cell are known as *plates* of the cell Thus the copper plate is a positive-plate, and the zinc-plate is a negative-plate in the cell. When the two plates are connected by a wire, electrons flow through the wire from the negative to the positive plate, or current flows from the positive to the negative plate This flow or current continues until the zinc plate is completely used up by this chemical action.

Polarization· As the chemical action within the sample cell continues, the electrons, which are removed from copper, combine with hydrogen-ions, forming molecules of hydrogen gas The gas coats the copper and gradually lowers the voltage of the cell, because the gas-coating hinders the chemical reaction which is necessary to bring the plates to the required potential difference This process is called polarization This should be prevented.

The amount of e.m f. that a cell can produce depends upon the materials of the plates and electrolytes. The amount of current a cell can deliver depends on the size of the plates. Although cells, used in practice, are made of different sizes and materials, the process of the production of voltage is the same. This is by the chemical action that removes electrons from one plate and adds electrons to the other.

Dry-types: In dry cells, the negative plate or electrode is a zinc container, and the positive electrode is a carbon rod that is placed in the centre of the container. An absorbent material is saturated with the electrolyte and then placed in contact with the plates or electrodes. A mixture of 'sal ammoniac' and 'zinc chloride' forms the electrolyte of an ordinary dry cell Fig 3.2 shows the construction of a dry cell.

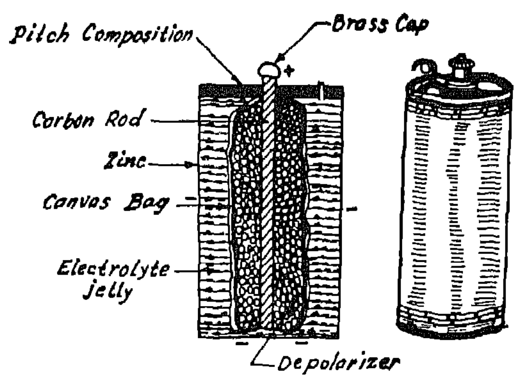


Fig. 3.2. Construction of a Dry Cell

Polarization takes place in a dry cell when the carbon electrode is coated with hydrogen gas during the operation of the cell. To remove the gas, a depolarizing mixture containing manganese dioxide is placed within the cell. The oxygen of this material combines with the hydrogen to form water. This action depolarizes the cell and enables the cell to give much better service.

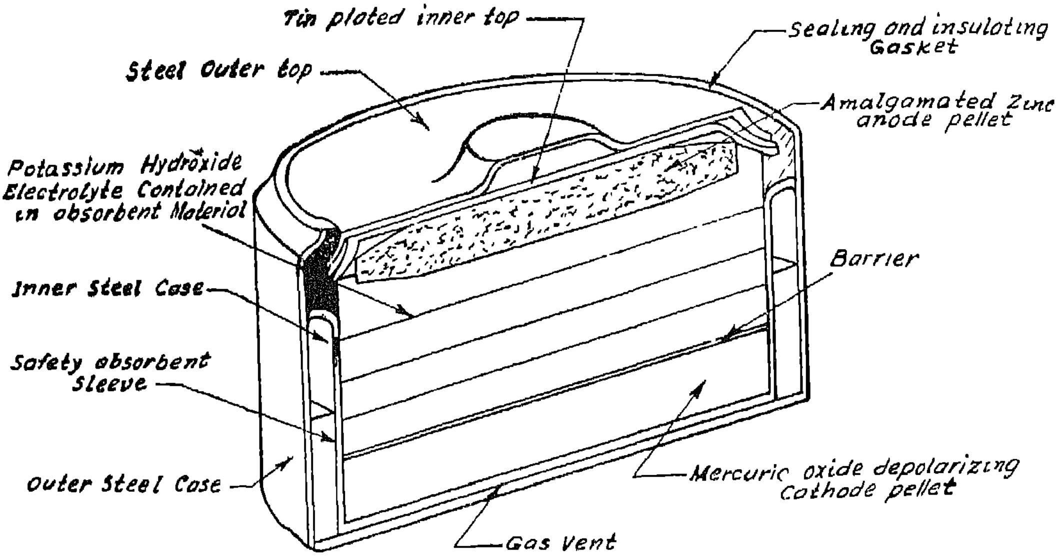


Fig. 3.3. Construction of a Mercury Cell

Dry cells are made of many sizes depending upon the nature of application. They are used in flash-lights, electric lanterns, flash-cameras, portable radios, hearing aids and many other devices

Dry cells employing the above chemicals, whether large or small, give an e.m f. of 1.5 volts The amount of current output depends upon their size The large cell can deliver larger current. If one cell is not enough for the required voltage, a larger voltage can be obtained by connecting a number of cells in series, and a larger current can be obtained by connecting a number of them in parallel.

A dry cell cannot be re-charged and put back into good condition after it has become dead or discharged after use. To obtain the best service out of a dry cell, the cell must not be used for large currents of longer duration. It should be used intermittently for a short period of time which permits it to depolarize and thus improve its condition of operation. A *dry-battery* consists of a number of dry cells placed within a battery 'Peck' and inter-connected in a suitable manner to give the required voltage and current output The batteries are made in several sizes to give 6, 9, 22 5, 67 5 or 90 volts

3-4. Mercury Cells and Batteries

Construction of a mercury cell is shown in Fig 3.3 These cells produce a voltage of approximately 1 4 volts. They last long and are particularly useful under conditions of high tempera-

ture and humidity Mercury batteries are used in transistor radios, walkie-talkies, hearing-aids and other types of portable electronic appliances They are usually made of several sizes like 4, 6, and 9 volts.

3-5. Secondary Cells

A secondary cell is a cell that can be charged and re-charged so that it can be used over and over again until its natural wear renders it inefficient. It is also called a *storage cell* since it can be thought of as a reservoir of chemical energy. Chemical energy is stored in the cell as electrical energy by charging it with direct current When energy is taken out of it in the form of direct current, it is said to be "discharging." Whenever the cell is found discharged, it can be re-charged or re-energized, restoring it to its original condition

The Lead-acid Cell· A Lead-acid Cell is the most common type of storage cell (shown in Fig 3 4). The electrodes or plates of the cell are made of some active materials, which take part in the chemical reactions, placed in a grid which provides mechanical support for

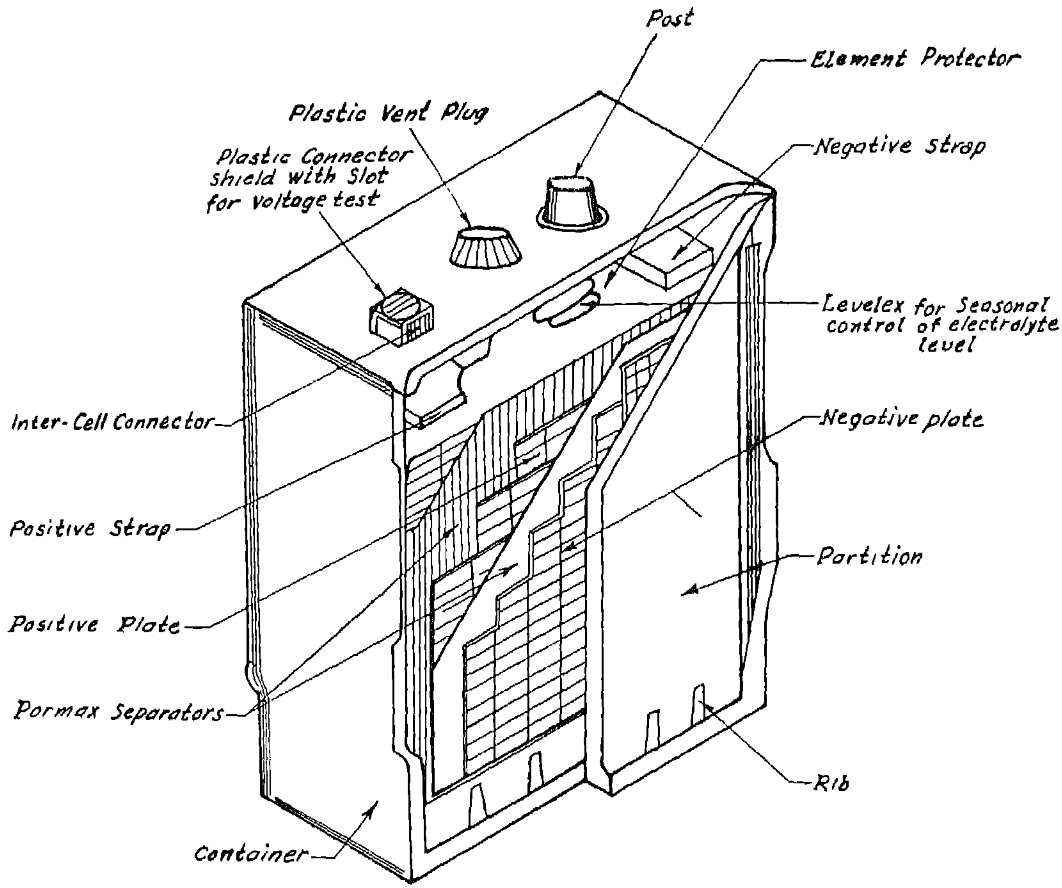
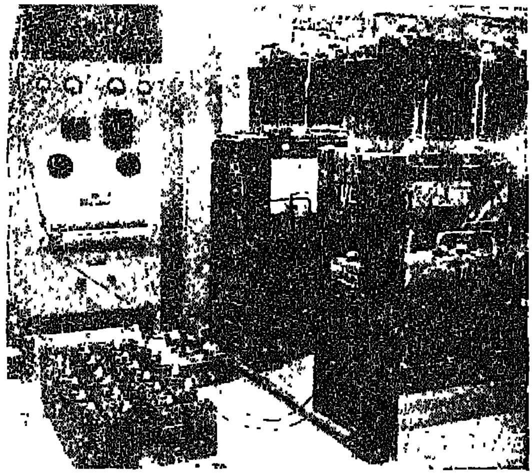


Fig. 3.4. Construction of a Lead-acid Cell

active materials and do not take part in chemical reactions. When fully charged the active material on the positive plate is *lead peroxide* The active material in the negative plate is *sponge lead* The plates are placed in electrolyte consisting of a solution of water and sulphuric acid. On full charge, the electrolyte contains about 27% acid by volume The cell gives an e.m.f of about 2 volts

The Lead-acid Battery· The automobile battery is the most common type of lead-acid battery There are three or six cells connected in series in such a battery, which makes available a voltage of 6 or 12 volts. The current-capacity of this battery depends upon the size and number of plates in each cell. The capacity is usually given in *ampere-hours.* For example, if a battery gives 10 amperes of current for 10 hours, or 5 amperes of current for 20 hours, the ampere-hour capacity of the battery is 10×10 or $5 \times 20 = 100$ ampere hours.



A Battery Room with the Charger

The Battery Charger: A storage battery is charged by passing direct current through it in a direction opposite to that in which the current passes when the battery is discharging. This is done by a battery charger which is nothing but a source of direct current voltage The charger is connected to a battery in like polarity (as shown in Fig 3.5) which means that the positive terminals are connected together and so are the negative terminals.

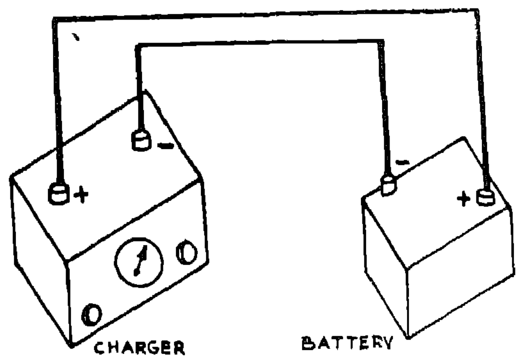


Fig. 3.5. Connection of Battery Charger to a Battery

Charging, Discharging and Hydrometer: When the lead-acid cell is discharging, the plates absorb the sulphuric acid within the electrolyte, as shown in Fig. 3.6 Since sulphuric acid is heavier than water, the weight of the electrolyte decreases as the cell discharges. This chemical action makes it possible to measure the condition, or the amount of charge, of a cell in terms of the specific gravity of the electrolyte The specific gravity of a liquid is the ratio of its weight to the weight of an equal quantity of pure water. A *hydrometer* is used to measure the specific gravity. Hydrometer-readings on charge and discharge are shown in Fig 3 7. In

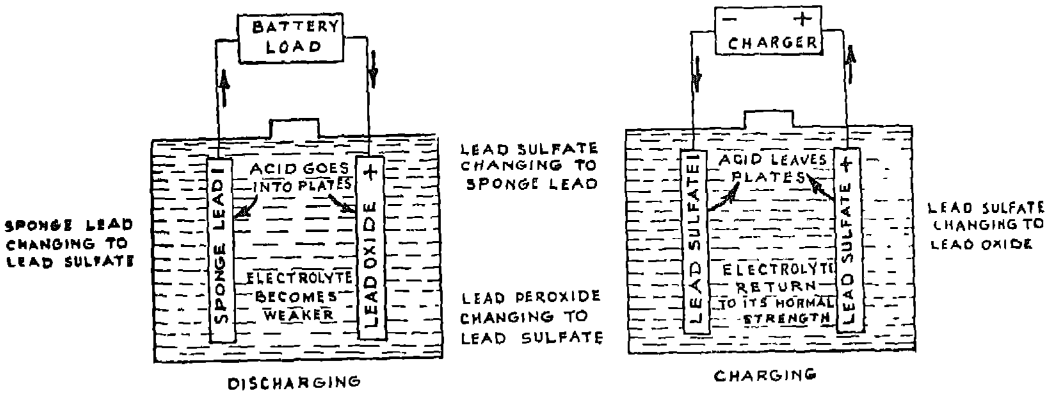


Fig. 3.6. Chemical actions in a Lead-acid Cell during Charge and Discharge

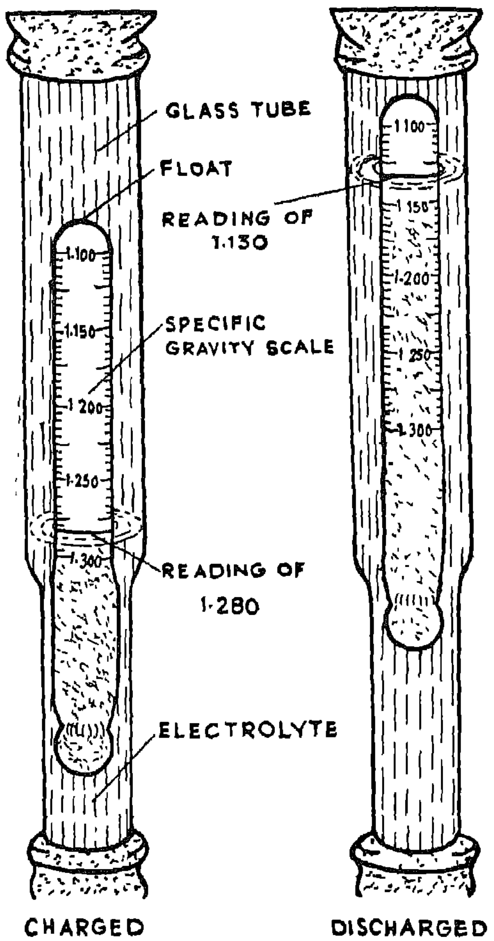


Fig. 3.7. A Hydrometer

a charged cell the reading of a hydrometer will indicate a specific gravity of 1.28 When completely discharged, the reading will show a specific gravity of 1 13.

3-6. Rules for using Lead-acid Battery

1. A battery should never be allowed to remain in a discharged condition for a long period of time. After full charging, it can be stored.

2. A battery should not be allowed to freeze. A discharged or nearly discharged battery will freeze at a temperature of–7°C and below

3. A battery should never be overcharged. This will weaken the electrolyte and may be detrimental to the cell plates.

4. An open flame should never be brought near a battery or cell that is being charged, as the hydrogen produced during this process may cause explosion.

5. The cells of the battery should always be kept filled with distilled water.

6. Only distilled or chemically pure water should be used for making the electrolyte.

7. While testing the battery-condition with the help of a hydrometer, the electrolyte should not come into contact with the body or clothing. In case of such contact taking place, the affected area should be cleaned with soap and water immediately

8. The connections at the terminals of the battery should be kept tight at all times.

9. To prevent the battery terminals from corrosion, heavy grease or petroleum jelly should be frequently applied

3-7. Internal Resistance of Cells

When the e m f of a fully charged cell is measured by a voltmeter across its terminals A and B with the cell being on no-load. it will indicate a voltage of about 2 volts But when a load (resistance) is connected across the cell and the voltage is measured across the same points, the voltmeter would indicate a lower voltage This is due to the voltage drop caused by load current flowing through the resistance of the cell, called *internal resistance*, as shown in Fig 3 8 (a) and (b). This is the resistance of the electrolyte between the two plates and of the plates and terminals all taken together. The internal resistance is lower when fully charged, but increases slightly on discharge This resistance causes a power loss in the battery and decreases its efficiency.

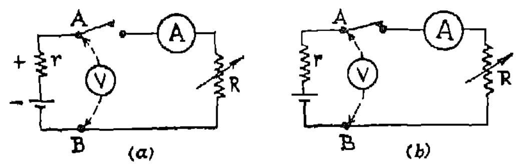


Fig. 3.8. Internal Resistance of a Cell

3-8. The Generator

With the establishment of the facts and laws of electro-magnetic induction by various scientists and engineers, the machine called *generator* was developed to convert mechanical energy into electrical energy At present, more than 95% of the electrical energy in the world is produced by such generators.

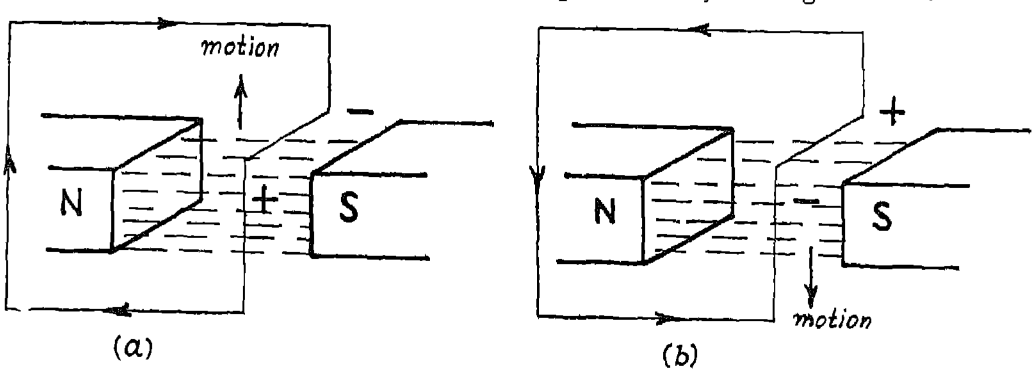


Fig. 3.9. Principle of Generator Action

Generatory Action: If a wire or conductor is moved across a magnetic field, there will be an e.m.f. of electro-magnetic induction in it. The direction of this e.m.f. can be determined from the laws of electro-magnetic induction given in Chapter 2. Figs. 3.9 (a) and (b) show the direction of the voltage by the positive and negative signs of polarity, and the direction of the current in the conductor loop, formed by joining the two ends of the conductor, by the arrow mark. The direction of motion in each case is as indicated. It will be seen that the direction of current reverses with the reversal of the direction of motion. The same result would be obtained if the conductor is stationary and the field is moving in such a way as to make the relative direction of motion remain the same. The magnitude of the voltage produced at any instant of time depends upon:

(1) the number of magnetic lines of force or the strength of the magnetic field, cut by the conductors,

(2) the speed at which the magnetic lines are cut, and

(3) the number of conductors in series.

3-9. The Alternating Current Generator

An alternating voltage can be continuously generated by rotating a coil of wire in between the two poles of a permanent magnet, as shown in Fig. 3.10. This is a simple generator. The coil, together with the core on which it is mounted (not shown in the figure), is called the *armature*. The two ends of the coil are connected to two copper *slip-rings*, which are insulated from each other and also from the armature shaft on which they are mounted. To enable the two ends of the rotating coil to be connected to external stationary circuit, one set of carbon brush is placed

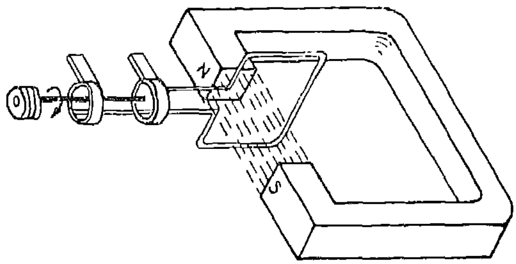


Fig. 3.10. A Rotating Coil between the Poles of a Permanent Magnet

in such a way as to make continuous contact with each of the slip-rings by sliding on their surface. With this arrangement when a load is connected to the external circuit, alternating current will flow through it when the coil is rotated by a drive called *prime mover*.

The drawings in fig. 3.11 show the generation of one complete *cycle* of current by a simple alternating current (abbreviated as A.C.) generator.

The first drawing indicates the position of the coil just before it begins to rotate in a clock-wise direction. At this instant there is no e.m.f. induced in the coil and so, no current in the load circuit, because the two conductors of the coil or 'coilsides' do not cut any magnetic lines of force (as each conductor moves parallel to the magnetic field).

As the coil moves from position 1 to position 2, the coilsides cut across the magnetic field and at the end of this position come to a point of maximum

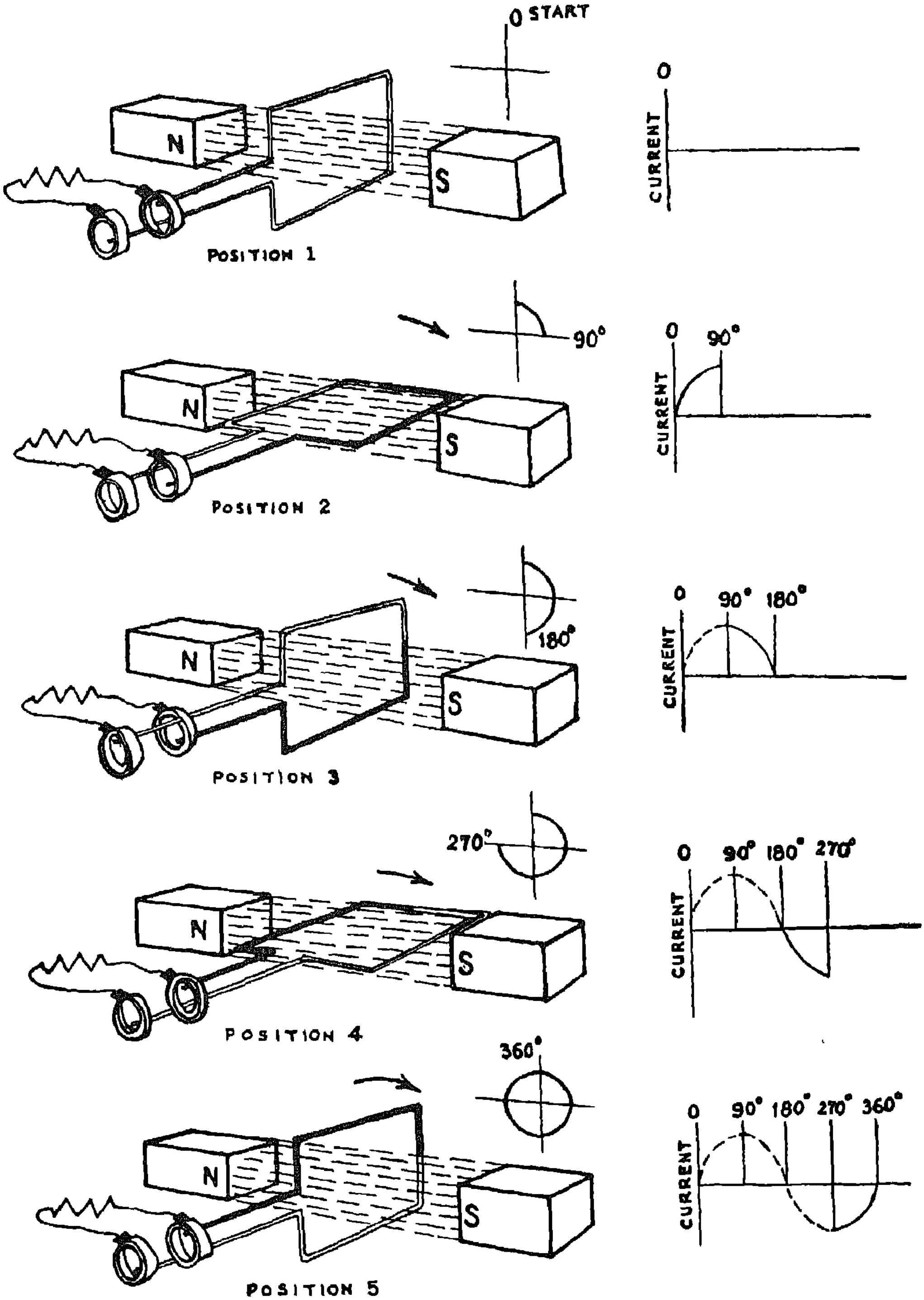


Fig. 3.11. Principle of Generation of Alternating Current

field strength As a result of this, the current increases during this interval from zero to its maximum value in one direction. This change takes place while the coil has rotated by 90^0 or a quarter of a cycle, and is shown by the curve

As the coil moves from position 2 to position 3, the current continues to flow in the same direction, because the direction of lines of force is still the same as it was between positions 1 and 2. But, again, at position 3 the coil does not cut any line of force; hence when the coil arrives at this position there will be no current in the coil or load circuit. So during the interval between position 2 and position 3, the current will decrease from its maximum value to zero, and will thus cover the second quarter of a cycle. The interval from position 1 to position 3 corresponds to a half-cycle.

As the coil continues to rotate to position 4, each coilside cuts the magnetic field in the opposite direction, and so the current flowing in the load circuit also gets reversed. During this interval the current again increases from zero to its maximum value, but in the opposite direction, and corresponds to the third quarter of a cycle.

Finally, as the coil moves from position 4 to the starting position 1, the current decreases from its negative maximum value to zero, and the interval corresponds to the fourth quarter of a cycle. Thus the interval from position 1, through positions 2, 3 and 4 and back to position 1, is one cycle.

3-10. The Direct-Current Generator

If the two slip-rings for the simple A.C. generator, mentioned earlier, are replaced by a commutator, the generator will supply *direct* or *unidirect* current in the external circuit to which it is connected. The simplest commutator is a split ring made of copper. The two segments of the ring, which are called commutator-segments, are insulated from each other and also insulated from the armature shaft The two ends of the armature coil are connected to two segments.

The operating principle of a simple direct-current generator is shown in Fig. 3.12 (a) and (b). Fig 3 12 (a) shows that when the coil is rotating clock-wise, from the vertical position corresponding to zero current, the generator will produce current in the direction as shown in the figure. During the time which the coil requires to make one half revolution, the current increases from zero to a maximum value and then comes down to zero. Also, during this period, the commutator segment A remains in contact with brush A and segment B with brush B As the coil begins the second half of its revolution, the connections of the segments with stationary brushes change so that, now, segment B comes into contact with brush A, and segment A with brush B, as shown in Fig. 3.12(b). During this interval the coilsides interchange their positions from under one pole to under another pole, thereby reversing the direction of current in them. But owing to a change in the contact of the segments with the brushes, the direction of current in the external load circuit connected across the brushes remains the same as before Although the value of the current changes from zero

to a maximum, and again to zero during the second-half revolution of the coil, the direction of current flow in the load-circuit does not change So we see that the commutator makes it possible to maintain the current in the external circuit in one direction, although the current in the coilsides are having current reversals as in the case of an A C. generator.

the *stator* and the rotating part (usually the field system) is called the *rotor*. Depending upon the type of the prime mover which drives a generator, alternators fall into two categories, namely, the *turbo-alternator* and the *hydro-electric generator*

Turbo-alternators are driven by high speed steam turbines The rotor is

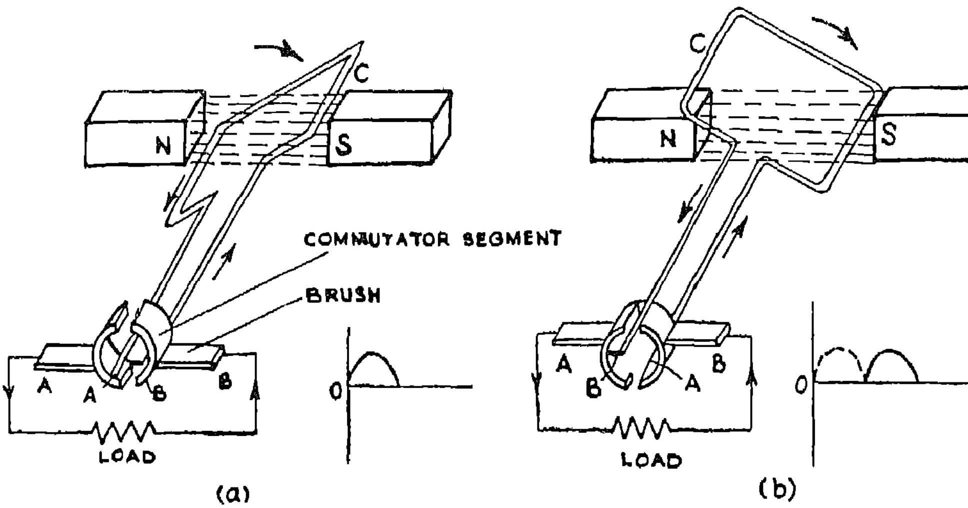


Fig. 3.12. Principle of Generation of Direct Current

3-11. Construction of A.C. Generator or Alternator

An alternator can be constructed either (i) with a rotating armature and stationary field system or (ii) with a rotating field system and stationary armature Theoretically, both types will give the same result But from practical considerations of insulation, current collection, mechanical rigidity, etc, the second type with rotating field system is commonly used for commercial alternators. The stationary part of the machine (usually the armature) is called

round and the air-gap between the stator (armature) and the rotor is uniform The rotor is usually made for two poles (one north-pole and one south-pole) The exciting winding or the coils which form the poles are placed in slots, cut on the solid rotor surface to a certain depth. Direct current is fed into the rotor windings through two terminals connected to two slip-rings. When current flows through the rotor coils, the rotor has magnetic field similar to that of a solenoid and forms the number of poles for which the rotor is wound.

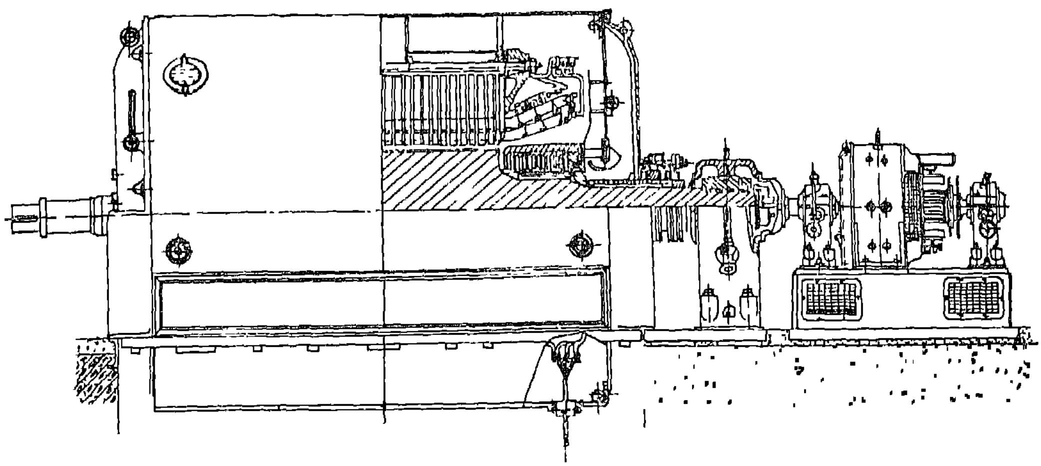


Fig 3.13 (a) Turbo-alternator
Fig. 3.13. Construction of A.C. Generators

Hydro-electric generators (also called water-wheel generators) are of medium and low-speed type, driven by water-turbines or pelton wheels The rotor of the field system is made up of a rotor-*spider* on which are mounted a number of poles called *salient poles*, as they project themselves out of the spider. The air-gap is not uniform The field-winding is a concentrated winding of insulated wires around the *pole-core*. The various parts of the rotor are shown in Fig. 3 13 (a) and (b) The field coils are usually connected in series and are supplied with direct current through the slip-rings

The source of direct-current for the field-winding is usually a D C generator coupled with the same shaft as the rotor, and driven by the same prime mover as the main generator This direct-current is called the *excitation current* as it excites the magnetic field by the poles

The *armature* or the stator of an alternator is the same for both round-rotor and salient pole machines The stator-core is made of sheet steel stampings stacked together to give the required shape of the slots and axial-length

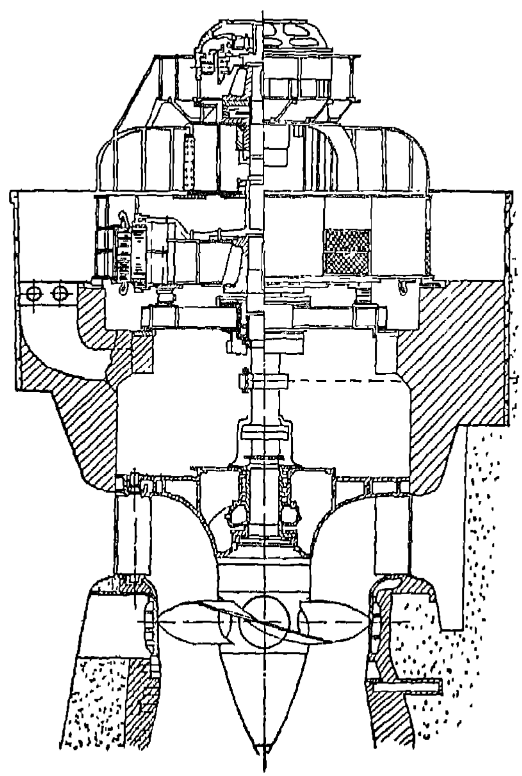


Fig. 3.13 (b) Hydro-electric Generator

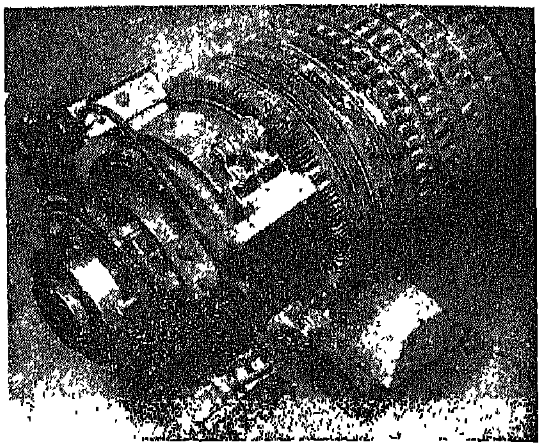
of the machine The shape of the slots is determined by the type of the armature conductor to be accommodated in them The conductors forming the *armature coils* are insulated by insulating materials, such as insulating paper and varnished cloth to withstand the required voltage between the adjacent coils and the coil and body of the machine There are some coils in the armature which depend upon the voltage and current output of the machine The mode of interconnection between them is determined by the type of *armature winding* adopted for the machine The size and shape of armature coil depends on the size of the machine. The armature, together with its windings, is supported by the frame which is usually fabricated from steel sheets for larger sizes.

Adequate provisions are made for the circulation of a cooling agent which is air in most cases For very large machines, hydrogen is used as a cooling medium. Cooling is necessary to keep the temperature inside the machines low, because a high temperature may damage the insulation. The temperature inside a machine increases on account of heat produced by the ohmic, iron, friction and windage losses

3-12. Construction of D.C. Generator

The constructional features of a D. C generator are shown in Fig 3.14) The D.C. Machine has a stationary field system and a rotating armature. It is necessary to have the armature rotating because of the commutator.

The D C machines may be of two or more poles The field system is similar to the salient-pole A.C generator type. There are some intermediate poles, called *interpoles*, in a D.C. machine, which are placed in between the main north and south poles. The main poles carry concentrated windings and are usually connected in series They receive their excitation current normally from the armature of the same machine



A D.C. Machine Armature

D.C. Generators may be classified as *shunt, series* or Compound-Generators depending on the mode of the connections of their field windings with respect to armature Fig 3.15 shows the three types of connections In all these cases the field windings are excited from their respective armatures. The field windings could also have been excited from a separate source of voltage. But this has not been found suitable owing to technical and economic reasons. The shunt field winding has a large number of turns of thinner wire, as a result of which its resistance is high and the current drawn from the armature small The series field winding has a small number

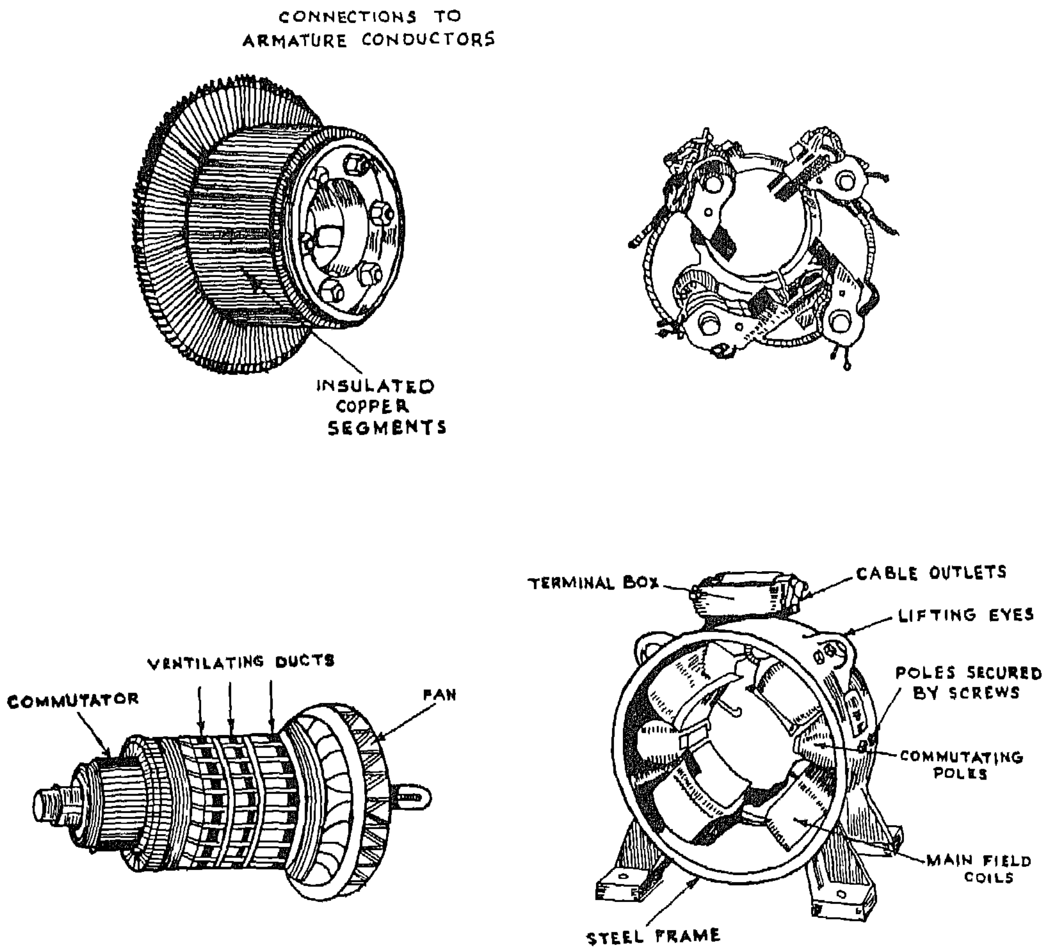


Fig. 3.14. Construction of a D. C. Machine

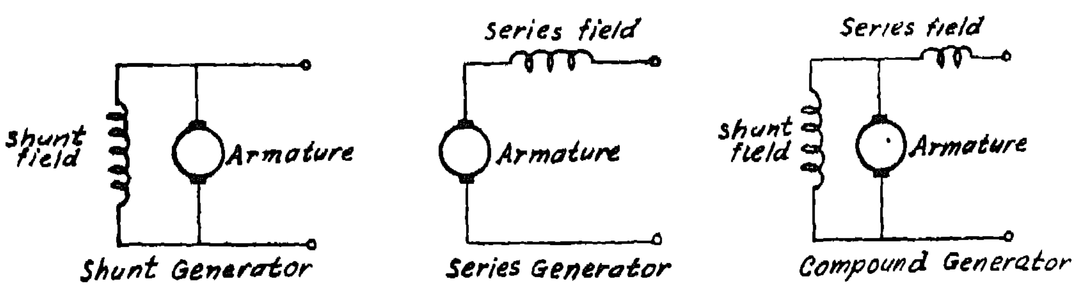


Fig. 3.15. Connections of Shunt, Series and Compound D.C. Generator

moves at the rated speed of the generator to a position where the coilsides occupy positions under the centres of the poles, the e.m.f. induced in the coil will increase from zero to a maximum value,

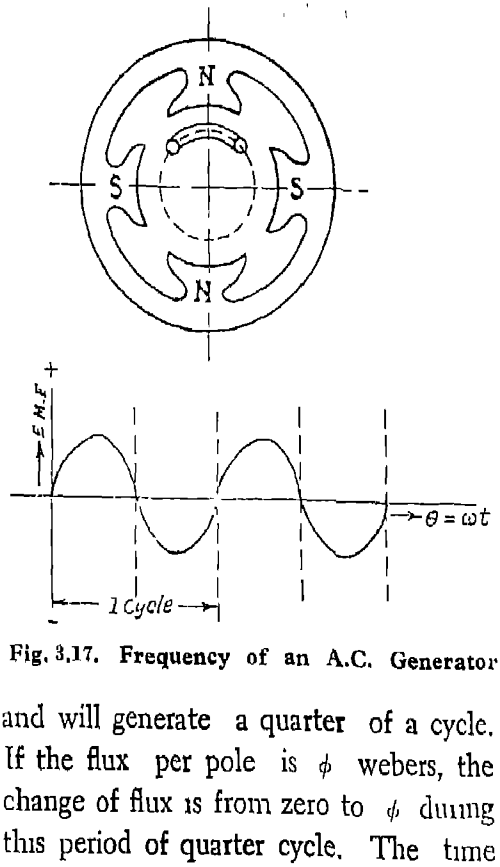


Fig. 3.17. Frequency of an A.C. Generator

and will generate a quarter of a cycle. If the flux per pole is ϕ webers, the change of flux is from zero to ϕ during this period of quarter cycle. The time required for one cycle is $\frac{1}{f}$ second; therefore, the time for one-quarter of a cycle is $\frac{1}{4f}$ seconds. Hence the average e.m.f. induced in a coil of one turn is

$$E_{av} = \frac{\phi}{1/4f} = 4\phi f \text{ volts}$$

poles and the armature, then the ratio

$$\frac{\text{Effective of R M.S. value}}{\text{Average value}} = 1.11.$$

Therefore $E_{r.m.s.} = 1.11$ Eav.

$= 4.44\ \phi$ Nf volts

for a single-phase generator, N will represent the total number of turns in series, and for three-phase generator N will be the number of turns in series per phase

Actually owing to the distribution of the coils in various slots, the e.m.f. induced, as given above, must be multiplied by a factor called "Distribution factor" (K_d)

Therefore, the e.m f induced becomes

$E_{r.m.s.} = 4.43\ K_d\ \phi$ N f volts.

The value of K_d may have an average value of 0.96.

3-16. Three-phase Voltage and Current

The simple alternator described earlier with one coil was a *single-phase* alternator. There was only one voltage in which the magnitude and direction changed every instant in a similar manner in every cycle In a simple three-phase alternator, as shown in Fig 3 18, there are three separate coils. As the armature rotates, three separate voltages are produced in the three coils. If the circuit of each coil is closed through a load (say a resistance), then three currents will flow in the three coils. This system of three voltages and currents is known as *three-phase* voltage and cur-

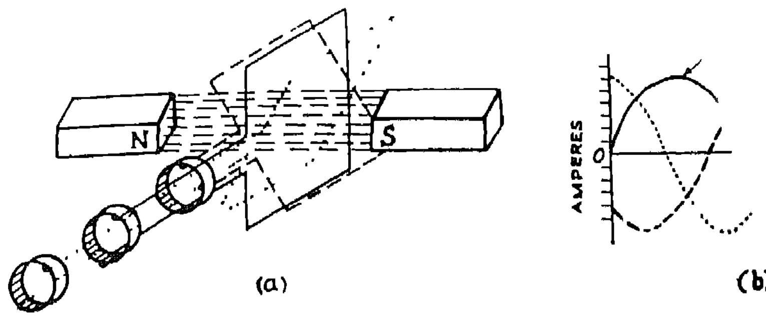


Fig. 3.18. Principle of Generating Three-phase Current

In practical three-phase generators, three separate sets of armature coils are used. All the currents are supplied to the generator load at the same time by means of a three-wire circuit. Three-phase currents are used by three-phase A C. motors.

3-17. The Alternating-Current Ampere

An alternating current is one in which the flow of electrons is in one direction during one half cycle and in the other direction during the next half cycle. This is repeated as many times per second as there are cycles per second. If the current one direction is said to be , then that in the other direction w be negative. The time-interval for one cycle is

$$T = \frac{1}{f} \text{ seconds, where } f = \text{frequency in}$$

cycles; sec.

so the duration of current flow in one direction is $\frac{T}{2}$ seconds. Most alternating currents and voltages vary according to a function known in trigonometry as a *sine*. That is why the positive and negative variations of the alternating cur-

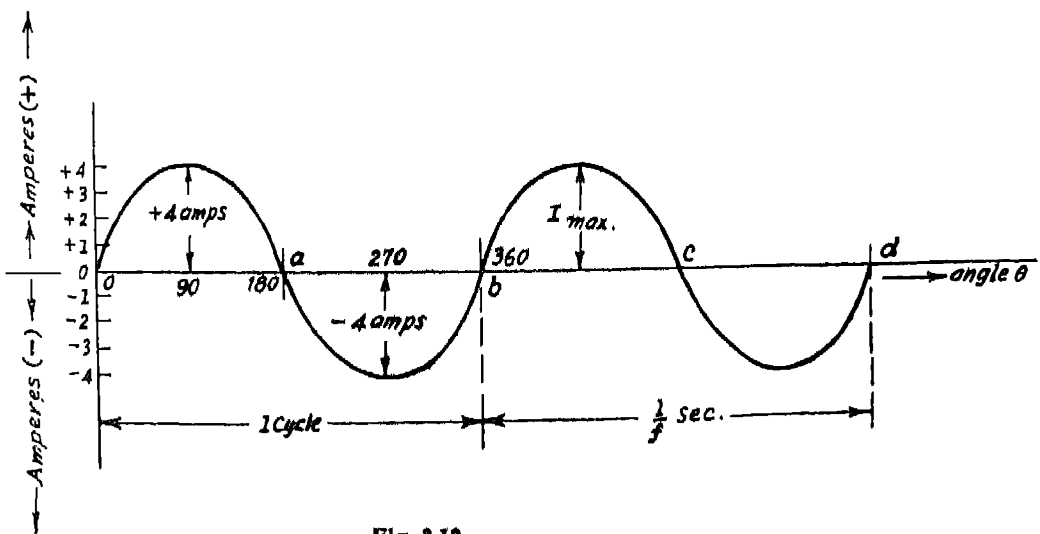
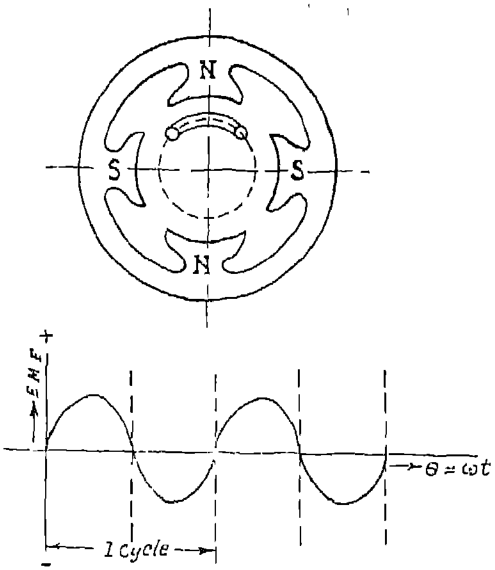


Fig. 3.19.

moves at the rated speed of the generator to a position where the coilsides occupy positions under the centres of the poles, the e.m.f. induced in the coil will increase from zero to a maximum value.



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$$E_{av} = \frac{\phi}{1/4f} = 4\phi f \text{ volts}$$

with N number of turns per coil,

$$Eav = 4\phi \text{ Nf volts.}$$

If the magnitude of the flux changes sinusoidally in the airgap between the poles and the armature, then the ratio

$$\frac{\text{Effective of R M.S. value}}{\text{Average value}} = 1\ 11.$$

Therefore $E_{r\,m\,s.} = 1.11$ Eav.

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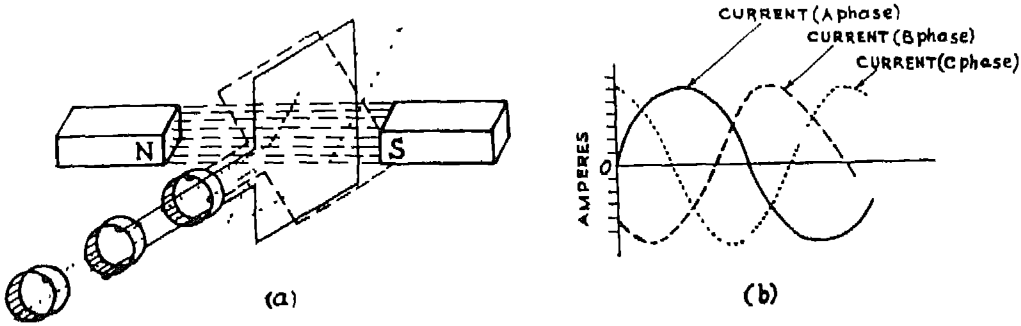

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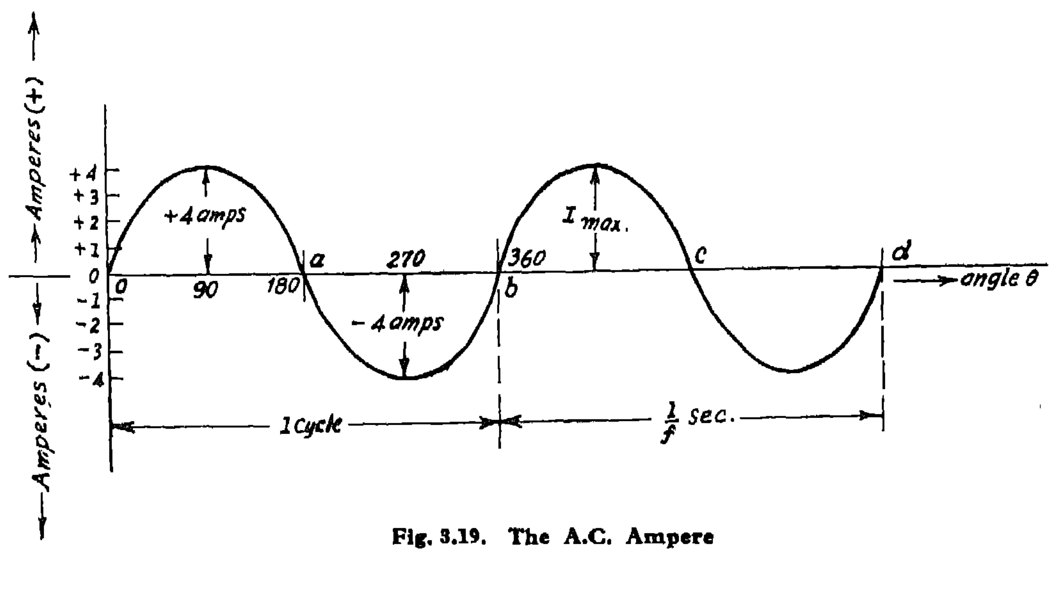


Fig. 3.19. The A.C. Ampere

rent is represented by a *sine-wave*, as shown in Fig. 3 19. One cycle is represented by 360 degrees. The current at any angle is given by

$i = I_{max} \sin \theta.$

At an angle of 90°, $i = I_{max} \sin 90° = I_{max}$.

At an angle of 270°, $i = I_{max} \sin 270° = -I_{max}$.

The angle $\theta = 2\pi$ f.t.

where t = time in seconds.

f = frequency in cycles per sec

So the current may be expressed as

$$i = I_{max} \sin (2\pi ft).$$

The A C. ampere is defined in terms of the amount of heat developed, because heat is produced in a resistor when alternating current flows through it in either directions Thus an *alternating-current ampere* is that current which produces heat at the same rate as a direct-current ampere through the same resistance.

It is known from the calculation for the sine variation of current that 70.7% or $\frac{1}{\sqrt{2}}$ of the maximum value of current is equivalent to a steady direct current, because both will produce heat at the same rate when flowing through the same resistance. If this effective heating current is called I_{eff}, then

$$I_{eff} = 0.707\ I_{max}.$$

This effective value is also known as the 'Root-Mean-square' value (R M S. value) Thus

$$I_{eff} = I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707\ I_{max};$$

similarly $V_{eff} = V_{rms} = \frac{V_{max}}{\sqrt{2}} = 0.707\ V_{max}$ for voltage.

All common A. C ammeters and voltmeters record r m s. amperes and r.m.s. volts respectively. Ordinarily, when we say so many amperes current or so many volts of voltage in A.C., it always means that they are r.m s or effective values.

3-18. Pure Resistance Circuit

When a source of alternating voltage is connected to a resistance R, the current is given by

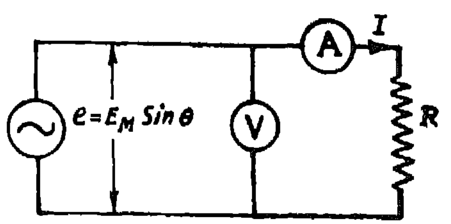
$$i = \frac{e}{R} = \frac{E_m}{R} \sin \theta = I_m \sin \theta$$

so that the maximum current $I_m = \frac{E_m}{R}$.

The ammeter will read a current of $\frac{I_m}{\sqrt{2}} = I$ amps the voltmeter will read a voltage of $\frac{E_m}{\sqrt{2}} = E = V$ volts, when the resistance R is in ohms From this again,

$$V = IR.$$

Fig 3.20 shows that current and voltage both reach their maximum and



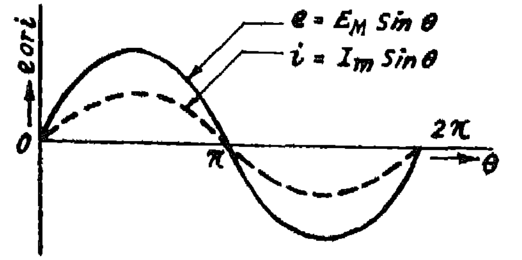


Fig. 3.20. An A.C. Circuit with only Resistance

zero-values at the same time. Under this condition it is said that the current is in phase with the voltage in a purely resistive circuit.

The power dissipated in the resistance is given by

$$P = I^2R = \frac{V^2}{R} = VI \text{ watts.}$$

3-19. Pure Inductive Reactance Circuit

If a coil is made of a thick wire with a large number of turns in such a way that its resistance becomes very small compared to the inductance, then the circuit will be like the one shown in Fig. 3 21(a). We saw in Chapter 2 that inductance opposes the change of current in a circuit, which makes the current lag the applied voltage In case of pure inductance this lag is 90^0, as shown in the curves in Fig. 3 21(a). Since in A.C. the voltage is constantly changing in every cycle, so the current at every instant in the coil will be lagging behind the voltage by 90^0

The magnitude of the current flowing on an inductive circuit depends on the 'inductive reactance' of the circuit and the applied voltage The inductive-reactance is given by

$X_L = 2\pi fL$ ohms, where L = inductance in henry
f–frequency in cycles per second.

When

$$e = E_m \sin \theta$$

$$i = \frac{E_m}{X_L} \sin(\theta - 90^0) \text{ where } I_m = \frac{E_m}{X_L}$$

$$= -I_m \cos \theta$$

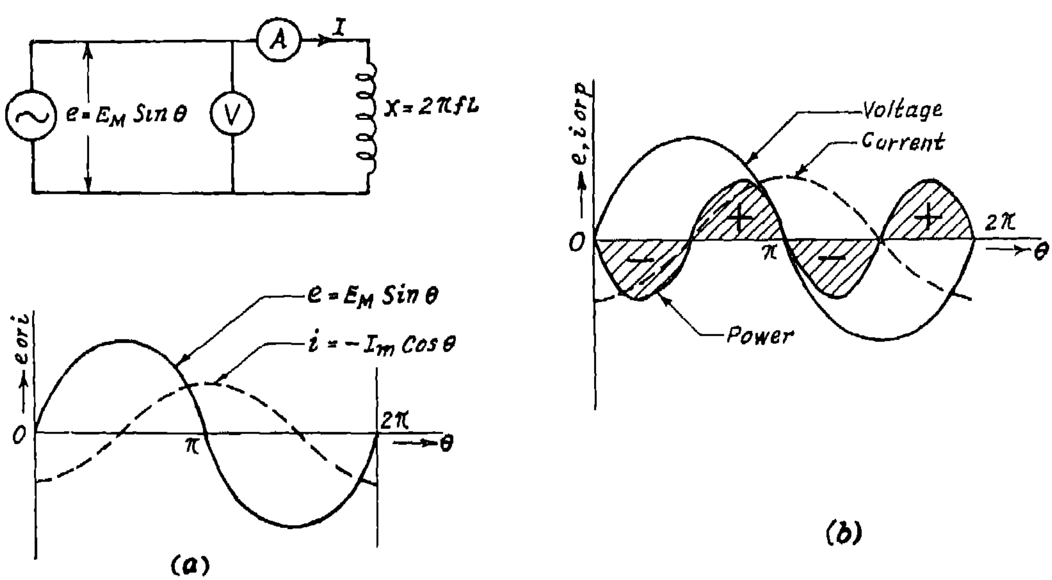


Fig. 3.21. A Purely Inductive A.C. Circuit

Therefore in a purely inductive circuit, in terms of r.m s values,

$$V = IX_L$$

where, V = applied voltage in volts.

I = circuit current in amps.

X_L = inductive reactance in ohms

Given the values of any two quantities mentioned above, one can easily calculate the third quantity

The power in any circuit at any instant is given by the product of the voltage and current at that instant Fig 3.21(b) shows the power variations with time in an inductive circuit One can see very easily that over a period of one cycle the average power is zero, because the total positive and negative areas over a cycle are equal. Hence we can say generally that the average power in a purely inductive circuit is zero, even though the current is flowing This is attributed to the fact that the resistance in this case has been assumed to be zero and hence power consumed I^2R is also equal to zero.

3·20. Circuit with Resistance and Inductance in Series

Let us consider a circuit containing both resistance and inductance in series The part of the circuit having both resistance and reactance is said to have an 'Impedance' Usually any inductance coil with a certain number of turns of wire will not only possess inductive reactance, but also a finite value of resistance In such a case the opposition offered for the flow of alternating current is called impedance The value of impedance can be obtained from the known values of resistance and reactance Thus

$$\text{impedance } Z = \sqrt{R^2 + X_L^2} \text{ ohms.}$$

where both R and X_L are in ohms

Fig 3 22(a) shows such a circuit We have seen earlier that the current is in phase with the applied voltage in the purely resistive circuit, and lags by 90° in a purely inductive circuit. In an impedance-circuit, having both resistance and inductance, the condition for the current will also be an intermediate one, and the current will lag the applied voltage by an angle *less than* 90°. The larger the proportion of the resistance to the inductive reactance in the circuit, the smaller will be the angle of lag. The voltage and current equations will be given by

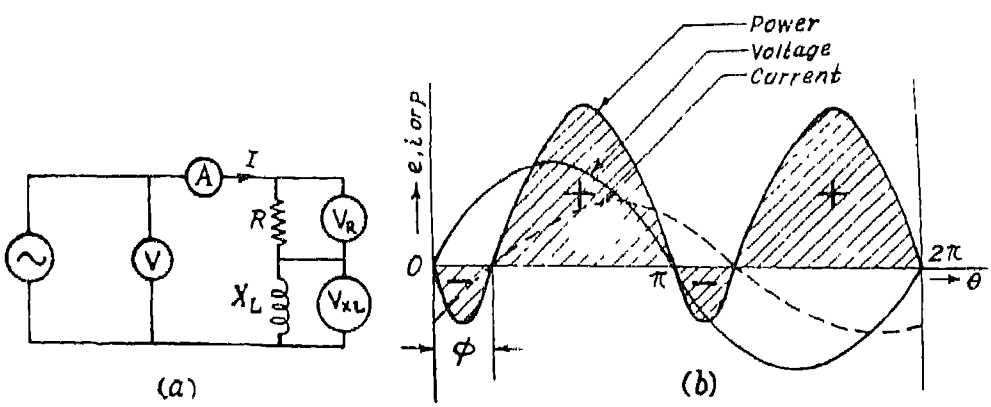


Fig. 3.22. An A.C. Circuit with Resistance and Inductance in Series

$E = E_m \sin \theta$

and $I = \frac{E_m}{Z} \sin (\theta - \phi)$, where ϕ is the angle of lag, given by $\tan \phi = \frac{X_L}{R}$

$= I_m \sin (\theta - \phi)$.

In terms of the r.m.s. values,

$V = IZ$

where V = the applied voltage in volts,

I = the circuit current in amps,

and Z = the circuit impedance in ohms

If the resistance and the inductive-reactance elements are separately connected in series, and if the voltages across them are measured, as shown in Fig 3 22(a), the voltage $V_R = IR$, and $V_{XL} = IX_L$, as the same current I flows through them as indicated by the ammeter A. But the voltmeter V will not read the simple sum of V_R and V_{XL}, as it would have done in a D C. circuit This is because of the 90^0 phase difference between the voltage drops V_R and V_{XL} developed across R and X_L by the current I. The reading of the voltmeter V in terms of V_R and V_{XL} may be determined in the following way:

$$V = IZ = I\sqrt{R^2 + X^2{}_L} = \sqrt{I^2 R^2 + I^2 X_L{}^2}$$
$$= \sqrt{(IR)_2 + \sqrt{IX)^2}} = \sqrt{V_R{}^2 + V_{XL}^2}$$

The angle of phase difference between I and V is given by

$$\tan \theta = \frac{X_L}{R} = \frac{IX_L}{IR} = \frac{V_{XL}}{V_R}.$$

The instantaneous power curve in the impedance circuit, as shown in fig. 3.22(b), has been obtained by multiplying the instantaneous voltages and currents In this case we see that the average power over a cycle is not zero The positive part of the power is much in excess of the negative part This means that there will be power loss in an impedance-circuit. The power is given by

$P = IV \cos \phi$ watts.

where V = Circuit current in amps.

I = Circuit current in amps.

and $\cos \phi$ = 'Power Factor' of the circuit,

The quantity 'Cos 'ϕ is called Power-Factor because in A.C circuits the power can be calculated only when the product of r m.s voltage (V) and current (I) is multiplied by this factor. We have seen in a D. C. circuit that power is given directly by the product of voltage and current.

The product of r.m s. voltage and current is sometimes called 'Apparent-Power' and is expressed in the unit of 'volt-amperes'. Thus, when the volt-amperes of a circuit is multiplied by the power-factor of the circuit, the power in the circuit is obtained in watts

Now, if we consider the power-factors of purely resistive and purely inductive circuits, we can see that:

(1) For the resistive case, $X_L = O$, so the angle ϕ is given by,

$$\tan \phi = \frac{X_L}{R} = \frac{O}{R} = O,$$

therefore, $\phi = O$

and $\cos \phi = 1$

so that the power $p = VI \times 1$ watts, as in the case of D. C.

(2) For the reactive case, $R = O$, so the angle ϕ is given by

$$\tan \phi = \frac{X_L}{O} = \text{infinity},$$

therefore, $\phi = 90^{\circ}$
and $\cos \phi = O$

Therefore, the power $p = VI \times O = O$.

Therefore, when a circuit does not contain resistance, there is no power loss. It follows that in a circuit containing reactance and resistance, power loss occurs only in the resistance.

Example: An impedance coil takes 400 watts of power and 5 amp from a 100 volt, 50 c|s source Calculate (a) the power-factor of the circuit, (b) the impedance, the resistance and the inductive reactance of the coil, and (c) angle of lag of the current.

Solution:

(a) Power factor $\cos \phi = \frac{W}{VI} = \frac{400}{5 \times 100}$

$= 0.8$ lagging Ans

(b) Impedance $Z = \frac{V}{I} = \frac{100}{5}$

$= 20$ ohms. Ans.

Since power loss takes place only in the resistance,

$$P = I^2R, \text{ or } R = \frac{P}{I^2},$$

Resistance $R = \frac{400}{(5)^2} = 16$ ohms. Ans.

And the Reactance $X = \sqrt{Z^2 - R^2}$

$= \sqrt{(20)^2 - (16)^2}$

$= 12$ ohns. Ans.

(c) The angle of lag is given by ϕ, where

$\cos = \phi\ 0\ 8$

Therefore from the trigonometric table of cosines,

$\phi = 36\ ^{\circ}9$ Ans.

3-21. Circuit with Capacitance

We have seen that current in a purely inductive reactance circuit lags behind the applied voltage by 90° There is another type of circuit containing Capacitor where the current *leads* the voltage by 90°. A circuit with capacitance and resistance is called a capacitive circuit.

A capacitor, which is also called a *condenser*, in its simplest form, consists of a pair of metallic plates separated or insulated from each other by a *dielectric* The dielectric is a non-conductor of electricity. The plates are commonly made of aluminium or tin (or any other non-magnetic substance) The dielectric may be of many different substances like air, gas, mica, glass, oil, wax and rubber When a D C source of potential is switched on to a capacitor, as shown in Fig. 3.23, a current flowing for only a short duration is indicated by the ammeter A in the circuit. When the current is no longer indicated, the switch is opened, and it will be observed that the voltmeter V will continue to show the voltage of the battery. This simple experiment proves that the capacitor, which was uncharged before the application of the voltage, became charged after the voltage was applied and the current flow for the short duration was

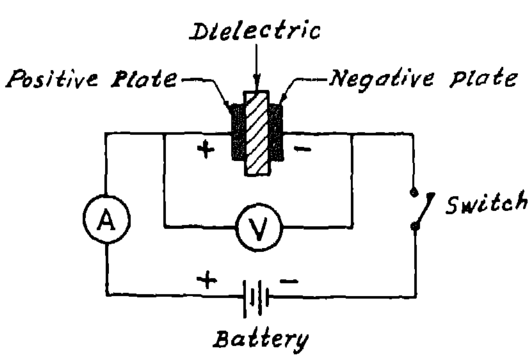


Fig. 3.23. A Capacitor Switched on to a Battery

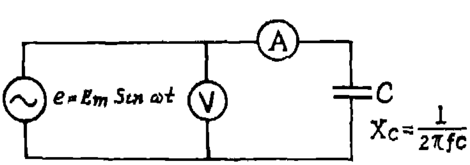
responsible for charging it Moreover, if the voltage across the capacitor and the charging current are measured instant by instant after the switch was put on, it will be seen that at the beginning, the current is maximum and, the voltage is zero As the time progresses, the current decreases and the voltage increases, and finally the current becomes zero when the voltage across the conductor is equal to the battery voltage This means that the current moves towards its maximum value before the voltage or, as the saying goes, the current leads the voltage

When an A C source of potential is connected to a capacitor, as shown in Fig 3.24(a), a similar phenomenon, as seen in D C will happen. What is remarkable in A.C. is that here the voltage applied changes its polarity every half cycle and its magnitude every instant according to a sine law. The curves of Fig 3 24(b) show the variations of voltage and current. In this case, in the first quarter of the cycle, the capacitor is charged because of the voltage increasing from zero to the maximum value, and the current decreasing from maximum to the zero value. In the second quarter of the cycle, the voltage decreases thereby discharging the capacitor and the current increases from zero to the maximum value in the opposite direction In the third quarter cycle, the capacitor is charged in the opposite direction, so that the current decreases from the negative maximum to the zero value. In the last quarter cycle, the capacitor, which was charged in the opposite (negative) direction, now discharges and so the current increases from zero to a maximum value in the positive direction Afterwards the same cycle of actions would follow

The magnitude of current flowing in a purely capacitive circuit will depend upon the value of capacitance of the capacitor. The capacitance or capacity of a condenser depends on the area of the plates and the *dielectric medium* For a given dielectric and its thickness, the capacity is directly proportional to the area of the plates. The unit of capacitance is *Farad*, but a smaller unit called *microfarad* is generally used.

1 microfarad (μF) = 10^{-6} farad (F)

If the value of a capacitance is C F, and the frequency of the applied



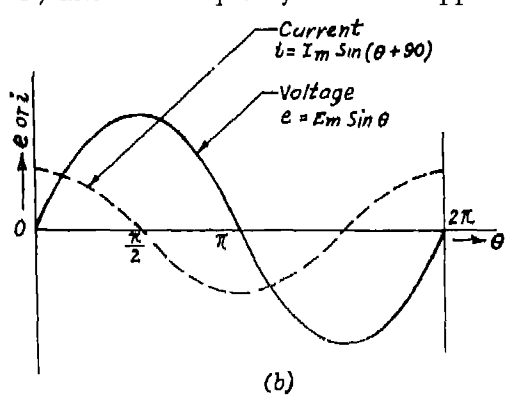


Fig. 3.24. An A.C Circuit with only Capacitance

voltage is f cycles per second, then the Capacitive Reactance of the capacitor is given by

$$X_C = \frac{10^6}{2\pi f C} \text{ohms.}$$

Let the applied voltage be $e = E_m \sin \phi$.

Then the current will be

$$i = \frac{E_m}{X_c} \sin(\phi + 90^\circ)$$
$$= I_m \sin(\psi + 90^\circ)$$

and $I_{r.m.s.} = \frac{I_m}{\sqrt{2}} = \frac{E_m}{\sqrt{2}\, X_c}$ amperes.

In terms of r.m.s values, if V is the applied voltage in volts, I the current in amperes and Xc the capacitive reactance in ohms, then

$$I = \frac{V}{X_c} = 2\pi f.\ C.V.\ 10^{-6} \text{ amperes}$$
$$= \omega CV.\ 10^{-6} \text{ amperes (because } \omega = 2\pi f).$$

3-22. Circuit with Resistance and Capacitance in Series

Let us consider a circuit containing both resistance and capacitance in series, as shown in Fig. 3.25(a). The impedance of this circuit is

$$Z = \sqrt{R^2 + K_c^2} \text{ ohms}$$

The current in the circuit will be given by

$$I = \frac{V}{Z} \text{amperes,}$$ with a phase-difference ϕ with the voltage so that

$$\tan \phi = \frac{X_c}{R}.$$

For a circuit with resistance and inductance in series the voltage-drops across resistance and inductance together do not give the total voltage, because of the phase difference between them. Here also, the voltage drop V_R across the resistance will be in phase with the curent I, and V_{XC} will be such that I leads V_{XC} by 90″. Therefore, the total voltage V read by the voltmeter will be,

$$= IZ = I\sqrt{R^2 + X_c^2} = \sqrt{I^2R^2 + I^2X^2_c}$$
$$= \sqrt{(IR)^2 + (IX_c)^2} = \sqrt{(V_R)^2 + (V_{XC})^2}.$$

The phase-difference between voltage and current will be given by

$$\tan \phi = \frac{X_C}{R} = \frac{IX_C}{IR} = \frac{V_{XC}}{V_R}.$$

The power-curve of the circuit is shown in Fig. 3.25(b) with voltage and current. This shows that the average power over a cycle is not zero. The

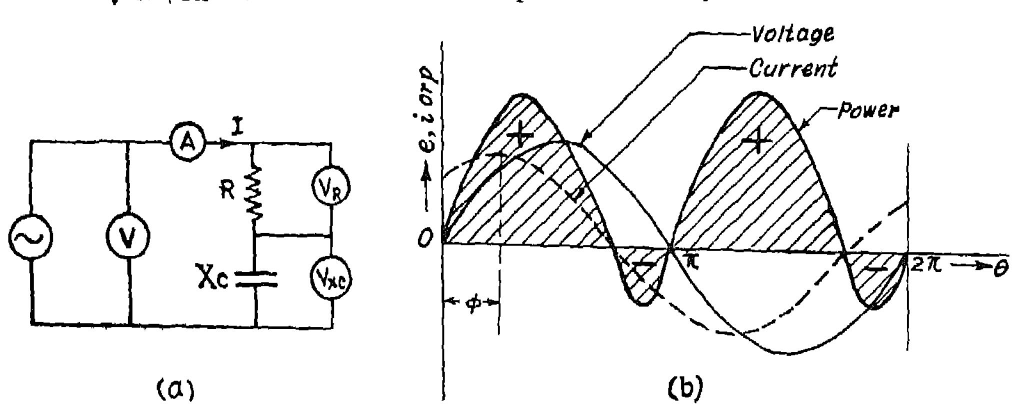


Fig. 3.25. An A.C. Circuit with Resistance and Capacitance in Series

positive part of the power is much in excess of the negative part The power loss in the circuit is given by

$P = VI \cos \phi$ watts

where $\cos \phi$ = power factor of the circuit.

Since there is no power loss in a pure capacitance, this power is lost in the resistance alone. Hence the power can also be represented by

$P = I^2R$ watts.

Example·

A series-circuit comprising a resistor of 12 ohms and a capacitor of 199 microfarad (μF), is connected across a supply of 100 volts, and of frequency 50 cycles per second Determine (i) the capacitive reactance and impedance of the circuit, (ii) the current, (iii) the power-factor and (iv) the power consumed in the circuit.

Solution:

(i) The capacitive reactance $X_c = \dfrac{10^6}{2\pi fC}$

$$= \frac{10^6}{2 \times 3.14 \times 50 \times 192} = 16 \text{ ohms. Ans.}$$

The impedance $Z = \sqrt{R^2 + X_c^2} = \sqrt{12^2 + 16^2}$

$= \sqrt{400} = 20$ ohms. Ans.

(ii) The current $I = \dfrac{V}{Z} = \dfrac{100}{20} = 5$ amps. Ans.

(iii) The power factor $= \dfrac{R}{Z} = \dfrac{12}{20} = 0.6$. Ans.

(iv) The power consumed

$P = VI \cos \phi = 100 \times 5 \times 0.6$

$= 300$ watts. Ans.

also $P = I^2R = (5)^2 \times 12 = 25 \times 12$

$= 300$ watts. Ans.

3-23 Circuit with Resistance, Inductance and Capacitance in Series

Fig 3.26 shows a circuit with resistance R, inductive reactance X_L, and capacitive reactance X_C in series A voltage (r.m.s.) V is applied to the circuit from an A C source. Let the current in the circuit be I Then, the impedance of the circuit will be given by

$$Z = \sqrt{R^2 + (X_L - X_c)^2} = \sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi fC}\right)^2}$$

Here, L is the inductance of X_L and C is the capacitance of X_C. If L is in henries and C is in farads, X_L and X_C are in ohms; and as R is also in ohms, then Z, too, will be in ohms.

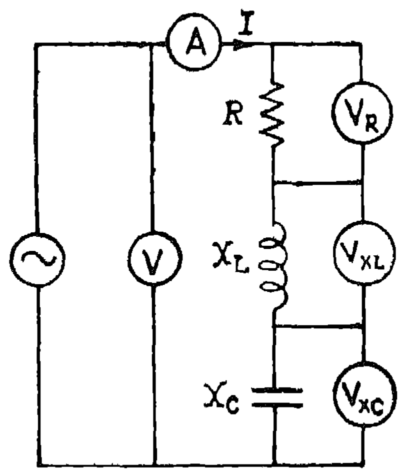


Fig. 3.26. An A.C. Circuit with Two Parallel Branches

The current in the circuit is

$I = \dfrac{V}{Z}$.

If V is in volts and Z is in ohms, then I will be in amps. The voltages across the resistor, inductor, and capacitor will be

$V_R = IR$; $VX_L = IX_L$; $VX_c = IX_c$.

The impedance in this circuit will be minimum when $X_L = X_C$; because under this condition $(X_L - X_C) = 0$ and the impedance $Z = R$. Therefore, the current in the circuit will be

maximum, and will be given by $I=\frac{V}{R}$.

The power-factor of the circuit will be unity, as the circuit will behave like a purely resistive circuit. The circuit will behave like an inductive circuit if $X_L \geq X_C$, and like a capacitive circuit if $X_C > X_L$.

There may be circuits where any of the three quantities R, X_L and X_C can be varied separately or simultaneously. Under such conditions, the impedance of the circuit can be adjusted to give any value and any power-factor, both leading or lagging. The circuit elements can then be called variable resistor, variable inductor or variable capacitor. The variations in X_L and X_C can be produced by varying the values of L and C or by varying the frequency of the supply.

Example :

A series circuit consists of a resistor of 3 ohms, an inductor of 3.82 henrics and a capacitor of 199 microfarads. This circuit is connected to a supply of 10 volts at 50 c|s frequency.

(i) Determine the current in the circuit and the voltages across the three circuit elements. (ii) For what value of the inductance L will the current in the circuit be maximum if the values of resistance and capacitance remain the same? What will be the voltages across the circuit elements under this condition?

(i) The inductive reactance $=2\pi fL = 2\pi \times 50 \times 3.82 = 12$ ohms. Ans.

The capacitive reactance $= \frac{10^6}{2\pi fc}$

$$= \frac{10^6}{2\pi \times 50 \times 199}$$

$= 16$ ohms. Ans

The resultant reactance $X_L - X_C = 12 - 16 = -4$ ohms. Ans.

This means that the resultant reactance will be of a capacitive nature, because $X_C < X_L$

Thus impedance $Z = \sqrt{(3)^2 + (-4)^2}$
$= \sqrt{9+16}$
$= \sqrt{25} = 5$ ohms.

The current $I = \frac{V}{Z} = \frac{10}{5} = 2$ amps. Ans

The following will be the voltages across the three circuit-elements:

$V_R = 2 \times 3 = 6$ volts. Ans. $V_{XL} = 2 \times 12 = 24$ volts. Ans. and $V_{XC} = 2 \times 16 = 32$ volts Ans

One can observe from these three voltages that the voltages across the inductance and capacitance can exceed the value of the supply voltage.

(ii) For maximum current, impedance Z should be minimum, for which

$X_L = X_C = 16$ ohms.

The required inductance is given by

$2\pi fL = 16$, or $L = \frac{16}{2\pi \times 50} = 5.08$ henries. Ans.

The maximum current in the circuit will be

$$I_{max} = \frac{V}{R} = \frac{10}{3} = 3.33 \text{ amps. Ans.}$$

The voltages across the various circuit elements are

$$V_R = \frac{10}{3} \times 3 = 10 \text{ volts.}$$

$$V \times_L = \frac{10}{3} \times 16 = 53{\cdot}3 \text{ volts. Ans.}$$

and

$$V \times_c = \frac{10}{3} \times 16 = 53{\cdot}3 \text{ volts. Ans.}$$

So the voltage across the resistor is equal to the voltage of the supply, and the voltages across the inductor and capacitor are equal and have the maximum possible value at the given applied voltage under this condition.

3-24. An Inductive Circuit and a Capacitive Circuit in Parallel

Fig. 3.27(a) shows one circuit having a resistance R_1 and inductance L, in parallel with another circuit having resistance R_2 and capacitance C, both connected to an A. C. supply of voltage V. The currents in the circuits are I_1 and I_2 respectively Since the current in the inductive circuit lags the voltage, and leads in the capacitive circuit, current I_1 will lag, and current I_2 will lead the voltage V. The angles of lag or lead will depend upon the impedance or power-factor angles of each circuit respectively. Fig. 3.27(b) shows the variations of I_1, I_2, I and V with time. The currents I_1 and I_2 have been drawn with equal maximum values, and equal phase angle differences $(\theta_1 = \theta_2)$. The figure shows that the maximum value of the total current I is less than that of either I_1 or I_2 This means that since (R.M.S value) $= \frac{1}{\sqrt{2}}$ (maximum value), the total current I indicated by the ammeter (A) will be less than the currents I_1 and I_2 indicated by the branch ammeters. It was seen for D. C. circuits that the total current will always be the sum of the branch current taken together, and greater than each of the branch currents taken separately. In A. C. circuit also, this would have been so, if both the parallel circuits were either inductive or capacitive or only resistive But in the

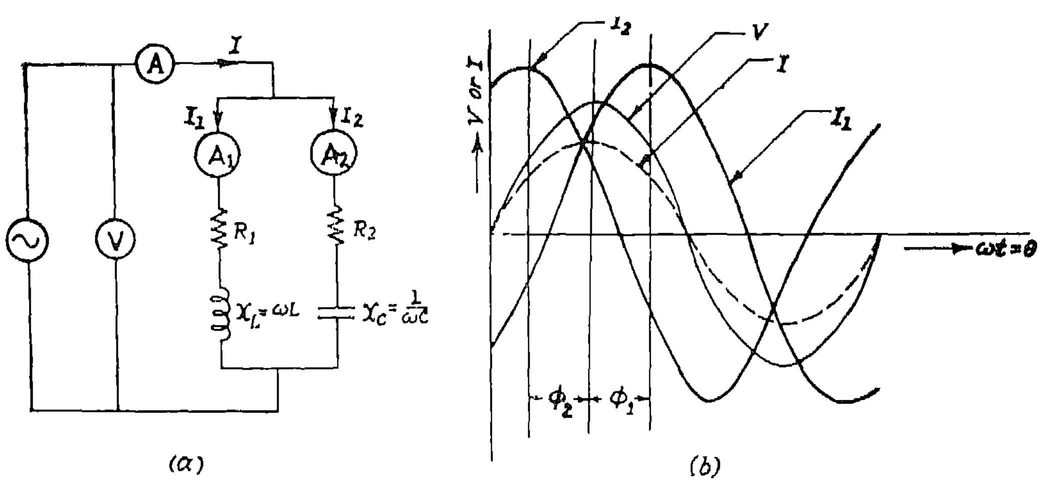


Fig. 3.27. An A.C. Circuit with Resistance, Inductance and Capacitance in Series

circuit of Fig 3.27(a) this is not so. It may be possible, therefore, to have a smaller total current than the sum of the currents in the branches of a parallel circuit if the individual branch circuits are inductive and capacitive in character.

3-25 Three-phase Circuit

We have so far considered only a single-phase voltage acting in the circuits containing resistance, inductance and capacitance A 3-phase voltage source supplies power to a 3-phase circuit, each phase may consist of one or more of the circuit elements (resistance, inductance or capacitance). The three phases of the generator or of the load may be connected in two ways, namely, in *Star* or in *Delta*. Fig 3 28 shows these connections. R, Y, B and A, B, C are *line-terminals* to which the phase-conductors are connected, and N is the *neutral point* or *star-point*. The voltage between any line-terminal and the neutral point is the phase-voltage (Vph) and between any two line-terminals is the *line-voltage* (V_L) The magnitudes of V_{ph} and V_L are given by $V_L = \sqrt{3}.\ V_{ph}$. Similarly, the line-current and the phase-current are given by $I_L = \sqrt{3}\ I_{ph}$. With star connection, $V_L = \sqrt{3}\ V_{ph}$, and $I_L = I_{ph}$, because the same current flows in the line and the phase, with delta connection, $V_L = V_{ph}$ and $I_L = \sqrt{3}\ I_{ph}$. The power in a 3-phase circuit, *whether in star or in delta*, is given by

$$P = \sqrt{3}\ V_L I_L \cos\theta$$
$$\text{or} \quad P = 3\ V_{ph} I_{ph} \cos\theta$$

where θ is the phase angle between the phase-voltage and phase current.

3-26. Transformers

A transformer is an apparatus by which voltages can be transformed from one value to another in A.C. circuits. A single phase transformer consists essentially of two windings linked by a common magnetic circuit, as shown in Fig 3.29 One winding, which is connected to the voltage source, is called the *Primary*, and the other winding, across which is connected the load, is called the Secondary. When A.C source of voltage is connected across the primary with no load on the secondary side, it draws a small current. This current will establish magnetic flux in the core. Since the current is alternating, the flux pro-

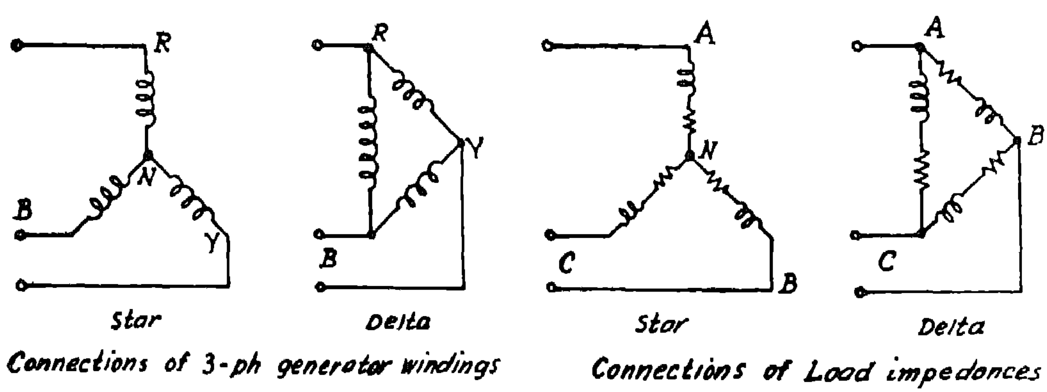


Fig. 3.28. Three-phase Circuit in Star and Delta

duced by it in the core will also be alternating. This mutual flux will link both the primary and the secondary windings and induce voltage in them. Let it be assumed, at first, that there is no load across the secondary and its terminals are open The primary induced voltage will be opposed by the applied voltage. The former, however, will be equal in magnitude to the latter As shown for alternators, this induced voltage will be given by

$$E_1 = 4.44\ \phi\ f\ N_1 \text{ volts}$$

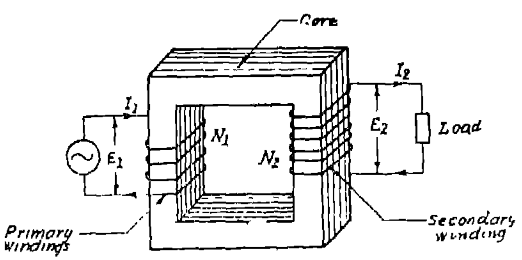
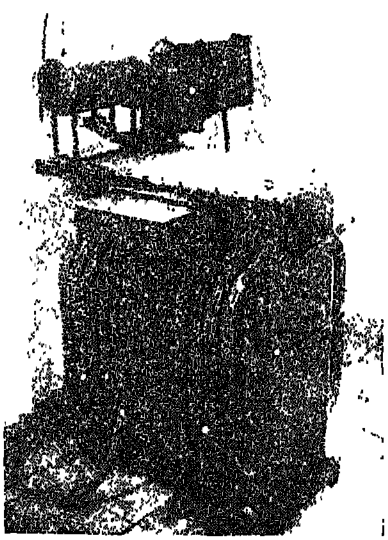


Fig. 3.29. Working Principle of a Transformer



A Power Transformer

Since the flux ϕ and the frequency f are the same for the primary and the secondary, the secondary induced voltage will be $E_2 = 4\ 44\ \phi\ f\ N_2$ volts.

Therefore, the voltages are proportional to the number of turns, or the ratio of the two voltages will be,

$$\frac{E_1}{E_2} \quad \frac{N_1}{N_2}.$$

This ratio is called the 'transformation ratio' By choosing the proper sized core and the ratio of turns, it is possible to have voltages stepped up or stepped down to required values. When a load (an impedance) is connected across the secondary winding, a current will flow in it. According to Lenz's Law, the direction of this current will be such as to oppose the cause which is producing it The cause of this current is the voltage induced in the secondary; and the voltage is induced by the mutual flux so that the secondary current must flow in such a direction that the flux produced by this current will tend to neutralize the mutual flux. As the mutual flux tends to decrease, it will decrease the induced voltage in the primary. Since the applied voltage remains constant, and the induced voltage in the primary tends to decrease, the difference between them increases, and this enables the primary winding to draw more current and produce more flux to counteract the tendency of the secondary to reduce the mutual flux. In fact, the fluxes are produced by the M.M.F s (as was shown in the earlier chapter) so that the secondary m.m.f. trying to neutralize the mutual flux I_2N_2 ampere turns. Therefore, the primary current has to attain such a value as to oppose this ampere turns. So we

have $I_2N_2 = I_1N_1$

or $\frac{I_2}{I_1} = \frac{N_1}{N_2}$ = Transformation Ratio.

It is seen that the currents in the primary and secondary are inversely proportional to their number of turns.

The power, at unity power-factor, in the secondary will be E_2I_2. If this is expressed in terms of the primary voltage and current, the relationship between the powers of the primary and secondary will be known. Therefore

$$E_2I_2 = \frac{N_2}{N_1} E_1 \frac{N_1}{N_2} = E_1I_1.$$

This shows that the power on the two sides is equal In fact, the secondary power output will be a little less than the primary power input, because of losses that take place in the transformer. The losses consist of the iron--losses in the transformer core, and the ohmic losses in the copper of the primary and secondary windings.

The construction of transformers varies according to their power capacities and application. Small transformers of a few watts' rating, such as those used in the radio and other domestic low-voltage applications, are made of small rectangular magnetic cores with windings, of thin insulated wires, mounted on their limbs. Large transformers with higher voltage and power ratings have a complex construction, because of the problems of insulation against high voltage and dissipation of losses which takes place within the transformer to keep down the temperature to a safe limit. The transformer core with its windings are placed in a metallic tank filled with insulating oil The oil also serves to take the heat out of the core and windings to the tank wall from where it is dissipated to the outer atmosphere To make the cooling more efficient, steel tubes and fins are fitted on the tank walls, which increase the effective surface area for better dissipation of the heat

For use in the 3-phase systems, 3-*phase transformers* are made by having a core with three limbs, each limb carrying a primary and a secondary winding These windings can be connected either in star or in delta. It is also possible to use three single-phase transformers in a 3-phase circuit by connecting their primary and secondary windings either in star or in delta.

3-27. Electric Motors

Earlier in this chapter we saw that an electric generator develops voltage, thereby resulting in current flow in the electrical circuits connected externally The power consumed in the external circuits is supplied by the generator In fact, the generator receives mechanical energy from the prime mover and converts it into electrical energy. The reverse transformation, that is conversion of electrical energy into mechanical energy, is possible for an electric motor. An electric motor receives electrical energy from a source of electric supply and develops torque necessary to rotate mechanical loads connected to its shaft. Electric motors have two major classifications depending upon whether their source of power is D.C. or A.C.

3-28. D.C. Motors

D.C Motors are used in electric

trains and train-cars, and also in the industry where smooth and effective speed control is necessary. In construction the D C. Motor is similar to the D.C. generator, excepting a few modifications as required in certain applications of the motor.

In Chapter 2 we saw that a current carrying conductor placed in a magnetic field experiences a force. As the Left Hand Rule states, the directions of the current, the magnetic field and the force will be at right angles to one another

Fig. 3 30 shows an elementary D C. motor N and S are the stationary north and south poles, which produce the necessary magnetic field in the motor A coil is placed in two slots cut on the armature, so that when one coil-side passes through the centre line of a north-pole, the other passes through the centre line of a south-pole When the coil is connected to an e.m.f. source, a current will pass through it, and the current will enter by one coil-side and return by the other, as shown in the figure The direction of the force experienced by each conductor at the position shown is indicated by the arrow Since each coil-side carries equal current, and is placed at position of identical magnetic field at given instant the two forces are equal in magnitude These two forces constitute a couple or torque, the value of which will depend upon the product of the force on each conductor and the distance between the coil-sides Since the armature is free to rotate, it will rotate in a clockwise direction, as shown in the figure. If there is only one coil, the torque produced will vary according to the positions of the armature conductor under the pole It will be at the maximum under

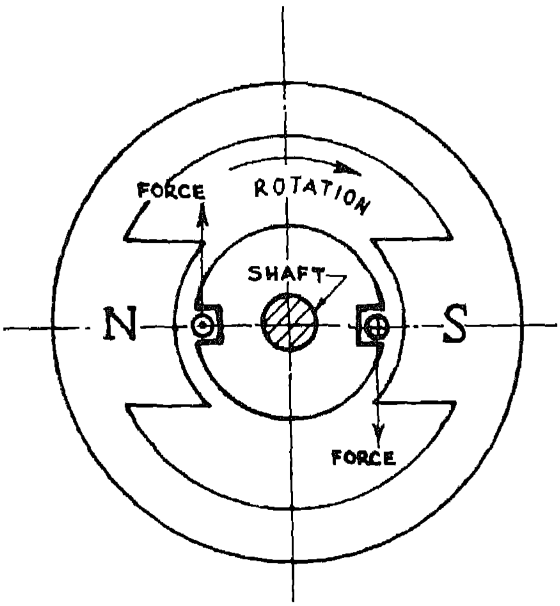


Fig. 3.30. Working Principle of a D.C. Motor

the region of the centre of the pole, and zero in the inter-polar axis or when the coil has rotated by 90 degrees from the position of maximum torque. In an actual motor, however, there is a large number of coils placed in a large number of slots on the armature periphery. At every instant, during the rotation of the armature, most coils will be under the poles linking flux, and very few coils will be in the inter-polar region without linking any flux Since armature coils are fed with current from the supply through the brushes and the commutator continuously, each coil develops a torque because of the current and the flux it links under the poles. The total torque developed by the motor is given by the sum of torques contributed by each coil. If the field strength and the current remain constant, the torque will also remain constant. This torque, developed by motor, is opposed by the torque of the mechanical load. Since the load-torque may

vary from time to time depending upon the actual application, the developed torque also must change to cope with it. The principle of this adjustment may be understood from the following considerations·

Let the motor be on no-load initially, and let it be connected to the supply Under this condition no mechanical torque is required and the motor is running light. If the strength of the magnetic field remains constant, the torque will be proportional to the current alone. Since at no-load no torque needs to be developed, the torque will be zero only when the current is zero. The current can be zero only when there is another voltage across the motor terminal equalling the value of the supply voltage but of opposite polarity This opposing voltage, known as the 'Back E M.F', is produced in the armature conductors on account of their rotation in the magnetic field, and its direction is given by the 'Right Hand Rule' and its magnitude will be proportional to the speed of rotation. This means that the back e.m f. exactly balances the applied supply voltage at no-load, and in the closed circuit of armature there is practically no current. Now if a mechanical load is connected to its shaft, say, a brake, the motor shaft must move against torque produced by the brake. To do this, the motor must develop torque to counter-balance the opposing load-torque on its shaft. Therefore, the motor armature must draw current from the source of supply. The motor can draw current only when the back e.m f. is less than the applied supply voltage which is usually assumed to be constant. The back e m.f. is reduced by the reduction in the speed of rotation The speed will reduce only by an amount which is just necessary to draw enough current to develop the required torque. Thus, the torque adjustment will be achieved only with a reduction in the value of back e.m.f, and in the speed reduction of the motor when the field strength remains constant A given value of back e m.f. can be obtained by any combination of speed and field strength, because it is directly proportional to both of them. Therefore, for a given load-torque, the speed of the motor can be varied by varying the field strength and the method is known as *Field Control.* From the same reasoning, it is quite clear that if the applied supply voltage across the armature is changed, the back e.m f must adjust itself to draw the requisite current from the source; and for a given value of field strength, this is possible only by a corresponding change in the speed Therefore, the speed of the motor can also be varied by varying the applied voltage to the armature, by putting resistance in series with it or by supplying from a variable voltage source, and this method is known as *Armature Control.* Usually, field control is used for increasing the speed and armature control for decreasing the speed fom its nominal rated value. The D. C. motors are further classified as shunt, series and compound motors, depending upon the method of connecting their field-winding to the armature. Fig 3.31 shows the connection diagrams of the shunt, series and compound motor. In the shunt motor, the field winding is connected in parallel to the armature, so that the same voltage is applied across the armature as well as the field-winding. In the series motor, the field winding is connected in series with the armature, so that the armature

and the field-currents are the same In the compound motor, there are two field-windings—each pole of the motor being excited by two field coils. One of the two windings is connected in series with the armature and is called the series *field*, and the other in parallel to it and is called the *shunt field*.

The performance of D C. motors is indicated by their operating characteristics. These characteristics show the variations of torque, speed, current and efficiency at various output-powers of the motor, and depend upon the type of the motor as to whether it is shunt, series or compound-wound. Each type of motor (shunt, series or compound) has similar characteristics, although the output-capacity or rating may vary over a wide range.

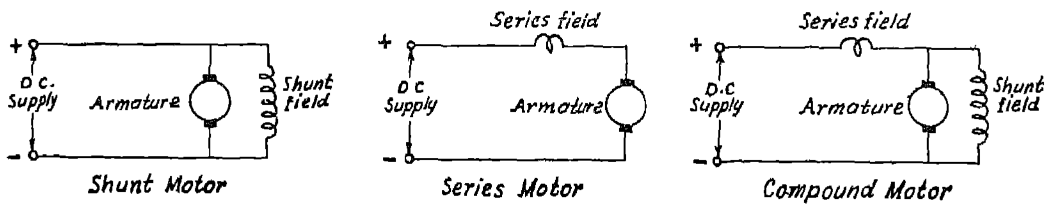


Fig. 3.31. Connections of Shunt, Series and Compound D.C. Motor

3-29 Torque Developed by D.C. Motor

We saw earlier that the magnitude of the torque developed by a D C motor will depend upon the force experienced by the various conductors and their distance from the centre of the armature. The force on the conductors (as shown in Chapter 2) depends upon the value of the magnetic field strength of the poles, and the current in them The current in each conductor depends on the number of parallel paths in the machine. So the torque developed by a D. C. motor can be expressed by the formula:

$$T=\frac{1}{2\pi}\cdot\frac{P\,\phi\,Z\,I_a}{a}\text{ newton—metres}$$

where

P=Number of poles in the machine
ϕ=Magnetic flux per pole, in Webers
Z=Total number of conductors in the armature
I_a=Total armature current, in Amperes
a=Number of parallel paths in the armature winding

3-30 Speed of D. C. Motor

While explaining the mechanism of the load adjustments of D. C motors it was shown earlier that the speed of the motor must change to draw the corresponding current with a change of load, and that this is accompanied with a change in the back e.m.f, which is given by (as shown for induced e.m f of generator):

$$E_b=\frac{P\,\phi\,n\,Z}{a}\text{ volts.}$$

If the applied voltage to the armature is V volts then the net voltage acting on the armature circuit to circulate current through the armature is

$$(V-E_b)\text{ volts.}$$

Therefore, from Ohm's Law, the current in the armature of resistance r_a is,

$$I_a=\frac{V-E_b}{r_a}\text{ amps}$$

$$\text{or}\quad E_b=V-I_a\,r_a\text{ volts}$$

$$\text{or}\quad \frac{P\,\phi\,n\,Z}{a}=V-I_a\,r_a.$$

Therefore, $n = \frac{(V - I_a r_a) \times a}{P \phi Z}$ revolution per second (r.p.s.).

3-31 D. C. Motor Starter

So far, the various aspects of the motor were being considered on the assumption that the supply voltage was always connected across the motor terminals Now let the case of a motor be considered while it is being connected to the supply to run it When a D C. motor is at rest (i.e., not running), there is no back e m.f., so that the voltage acting on the armature circuit is only the supply voltage V, and the current drawn by the armature will be V/r_a amperes. If the supply voltage is 220 volts and the armature resistance is 0.1 ohm of a motor of rated current, say 22 amperes, the current taken, just after the connection of the supply voltage and, before the motor has started to rotate, will be 220/0.1 = 2200 amps. This means that the starting current in the motor will be 100 times the normal full-load current of the motor. The armature of the motor is sure to get burnt with such a large current, because this current will flow for some time till the armature has gathered sufficient speed and back e m.f. to reduce this current. So a D C motor cannot be switched on directly to the supply, but some arrangement must be made to limit the current during the starting period of the motor During this period, it must develop enough torque to rotate and accelerate the armature with its mechanical load The apparatus by which this is achieved is called a stator

Fig. 3.32 shows a D. C, motor starter Besides incorporating methods of limiting the current under starting conditions, the following additional features for the protection of motor are added to automatically switch off the connection to the motor (i) whenever power supply fails and (ii) whenever the mechanical energy drawn from the motor exceeds the values for which it is rated. Now let us learn something about the various parts of the starter and their functions One armature terminal is connected to A and one field terminal to F of the starter The other armature and field terminals are joined together and connected to one terminal of the D. C supply The other supply terminal is connected to the handle-bar, which has an insulated knob, to be held with the hand, to move handle from "OFF" to "ON" position The handle has a piece of soft iron armature, which gets attracted by the no-volt release magnet when the handle is brought to the "ON" position against the torsion of the spring The spring always tends to keep the handle in the "OFF" position.

When the switch is put on and the handle is brought to the position 1, the positive terminal of the supply gets connected to terminal A through the handle and the starter resistances R_1, R_2, R_3 and R_4 series and to terminal F through the handle, the metallic piece and the "No-volt" release coil The negative terminal gets connected to the common terminal of the armature and the field. So current flows in both the field and the armature windings But the current in the armature is kept down to a low value by the series resistances R_1, R_2, R_3 and R_4, while the current in the field will have its normal value. The motor will now develop sufficient torque and start rotat-

ing. As the motor speeds up the back, e.m.f produced thereby will gradually decrease the armature current and the handle can be moved gradually towards the "ON" position by cutting out the resistance steps The handle remains in the "ON" position, because of the current flowing through the field winding In this position, the current in the field winding flows through the starter resistances, but since their combined resistance is very small compared to the resistance of the field winding, the field-current will be nearly the same as before. The motor now runs at normal speed with its mechanical load If there is an over-load on the motor, it will draw more current from the supply. If this current is sufficiently high to damage the motor, the 'over-load release' coil will be energised and it will close a contact which will bypass the current through the "No-volt" release coil. Without any current in this coil, it will lose its magnetism and release the handle, which comes back to the "OFF" position by the action of the spring and the motor is disconnected from the supply.

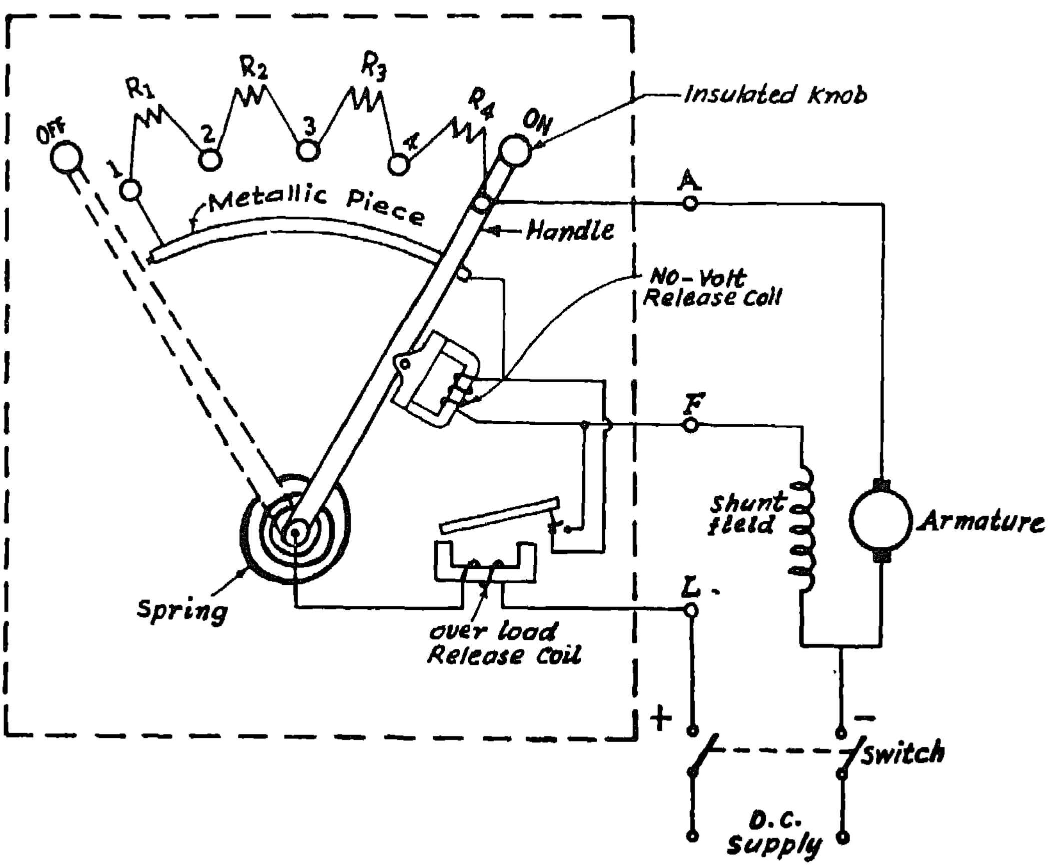


Fig. 3.32. Connection Diagram of a D.C. Motor Starter

3-32. A.C Motors

A C. motors are used extensively in the industry as well as for domestic use, as most of the electric power supply systems are generally A.C. There are various types of A.C. motors, depending upon the requirements of their use. Broadly, A.C. motors may be classified in two classes, namely, *Asynchronous* and *Synchronous*. The speed of asynchronous motors of a given frequency changes withc hange of load, while with synchronous motors the speed remains constant at a given frequency irrespective of the load-changes The most important and widely used asynchronous motor is the *Induction Motor.*

3-33. Induction Motor

The starter of a three-phase induction motor, together with its conductors forming a 3-phase winding, is similar to that of an alternator. Fig. 3.33 shows the construction of a 3-phase induction motor. The rotor may be of two types, namely, the *Squirrel-cage* and the *Wound-Rotor*. The squirrel-cage rotor is made by putting copper conductors without insulation in the rotor slots on its periphery and in an axial direction. The ends of all the conductors are joined together by two *end-rings* at the two ends of the rotor. When one sees only the conductors of the rotor with their end-rings, they appear to form a cage-like structure; hence the name squirrel-cage. The wound-rotor is made by having insulated conductors in the rotor slots arranged as a 3-phase winding, the three terminals of which are brought out to three *slip-rings* mounted on the rotor shaft This is why an induction motor with wound rotor is also known as *slip-ring motor* Three terminals of the external resistances in star can then be connected to the rotor circuit through three sets of brushes, for starting and speed-control. If no external resistance is used, the three slip-rings are short-circuited (joined together) to provide closed circuit paths to the rotor induced currents.

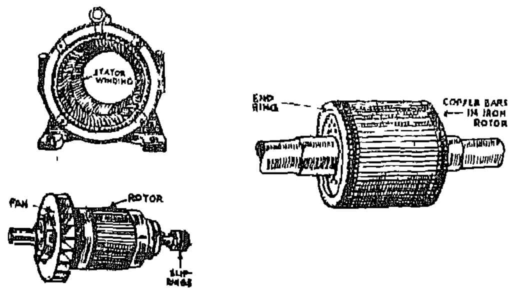
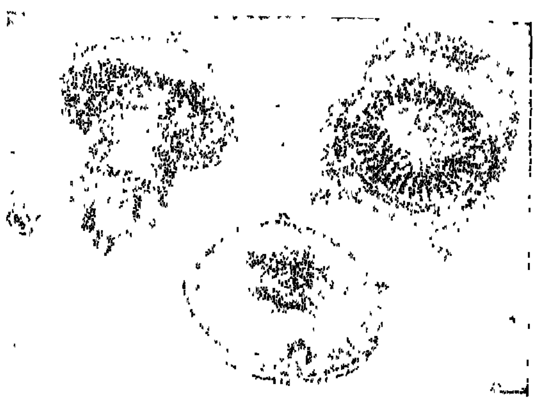


Fig. 3.33. Construction of Three-phase Induction Motor



Dismantled Parts of a 3-phase Induction Motor

The working-principle of the induction motor may be understood from the following:

In Chapter 2 we saw that a current flowing through a conductor produces a magnetic field. When the current is alternating, the magnetic field will also be an alternating one. When a 3-phase supply is connected to the three terminals of an induction motor, whose stator

may be connected in either star or in delta, 3-phase currents flow in the three phases of the stator winding, resulting in the production of three alternating magnetic fields in the stator simultaneously. These three alternating magnetic fields combine together to produce a *rotating magnetic field* of constant value in the stator. This means that, although the stator and stator-conductors are stationary, there exists, in effect, alternately formed north and south poles (as in the case of a solenoid), rotating along with the field produced by them in the airgap between the stator and the rotor. This rotating field cuts the rotor conductors and induces voltage in them. Since the rotor-conductors are connected in a closed circuit, current flows in them along with a corresponding current in the stator windings similar to the transformers. The effects of this current in the rotor can be seen by applying Lenz's Law, according to which the force and the torque, produced by the interaction of this current and the rotating magnetic field which is inducing it, must act so as to oppose the cause which is producing this current. The cause of this current is the cutting of the conductors by the rotating magnetic field. This can be opposed only by a rotation of the rotor in the same direction as the rotating magnetic field (see Fig. 3.34). This is so because, under this condition, the relative speed, with which the field cuts the conductors, decreases as the speed of the rotor increases. This results in the reduction of induced voltage in the rotor, thereby decreasing the rotor current with corresponding decrease in the stator. If there is no mechanical load on the rotor, no torque is present to oppose the rotation of the rotor, and so no current need flow in the rotor Therefore, the rotor induced-voltage may be zero, and the rotor speed becomes equal to that of the rotating magnetic field. When there is a mechanical load in the rotor, the motor must develop a corresponding torque, and the speed of the rotor must decrease to induce enough current necessary for running with the load. Since the speed under this condition is less than the speed of the rotating field, the rotor is said to *slip*. The more the load on the motor the more will be the slip, which is the difference between the actual speed of the motor and the speed of the rotating field. The speed of the rotating magnetic field depends on the number of poles for which the 3-phase stator is wound, and the frequency of the A.C. supply to which the stator winding is connected.

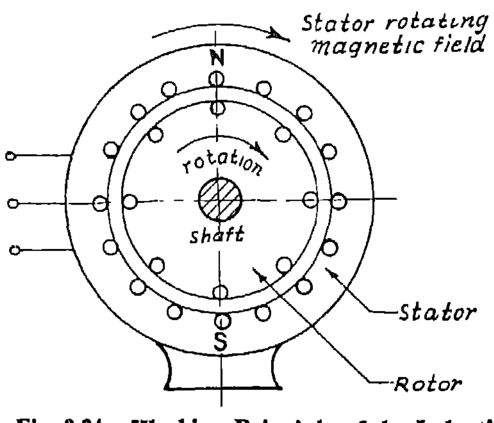


Fig. 3.34. Working Principle of the Induction Motor

The speed is given by

$$f = p.\ n \text{ cycles per sec.}$$

where p is the number of pairs of poles and n is the speed of the rotating magnetic field in revolutions per second. If the speed is to be obtained in revolutions per minute (Ns) and in terms of

the number of poles (P), then

$$N_s = \frac{120f}{p} \text{ rev. per min. (r.p.m.)}$$

It follows from this relation that the speed of the rotating magnetic field will be constant for a constant frequency and a given number of poles. This speed is called the 'synchronous speed' A 4-pole induction motor with a supply of 50 cycles per second frequency will have a synchronous speed of 120 x 5/4 = 1500 r.p m.

If the actual speed of a motor is N r p.m., then the slip-speed is (Ns — N) r p.m. When the slip-speed is expressed as a percentage of the synchronous speed, the slip (s) is given as percentage slip.

$$\%\text{slip} = \frac{N_s - N}{N_s} \times 100.$$

If the 4-pole motor, considered earlier, runs at 1470 r.p m. then the percentage slip will be

$$S = \frac{1500 - 1470}{1500} \times 1000 = \frac{3000}{1500} = 2\%$$

3-34 Induction Motor Starter

If, while starting, the motor is switched on to the full rated voltage, it may draw very large current which may be harmful to the motor itself, as well as to other apparatus connected to the same source of supply. Therefore, it is desirable that a lower voltage should be applied to the motor at the time of starting. This can be done by a 'Star-Delta Starter'. This starter connects the 3-phase winding of the stator, in star during starting, and in delta when the motor has attained an almost normal speed. By this the starting voltage is $\frac{1}{\sqrt{3}}$ times the voltage in the running condition of the motor. The motor can also be started with another type of starter, called 'Auto-transformer Starter' This also applies a reduced voltage during start and full voltage for run. Fig. 3 35 shows a star-delta starter.

In the 3-phase induction motor, starters are usually necessary for motors of larger power output. Small motors up to 5 kw. rating may be started directly on the mains without a starter, because small motors take less current and can speed up quickly.

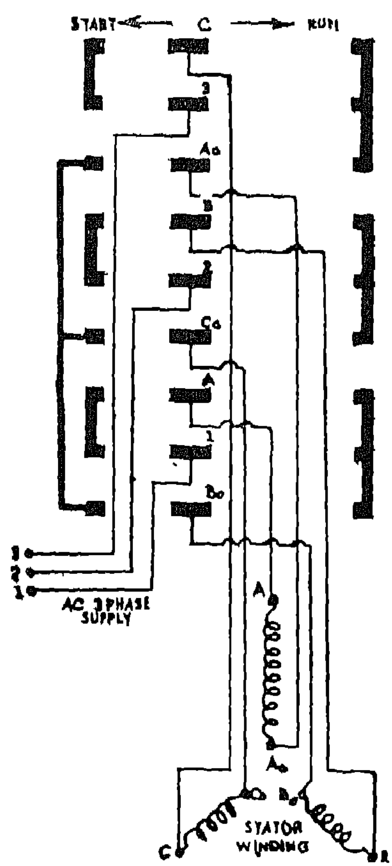


Fig. 3.35. Connections of a Star-Delta Starter

3-35. Single-phase Induction Motor

The construction of this motor is similar to that of a 3-phase motor except that the armature has a 1-phase winding With a 1-phase winding alone, the motor cannot start when switched on to a 1-phase supply. For this reason another winding, called *starting winding*, is placed in the armature slots with the other winding. In most motors, the starting winding is disconnected automatically as soon as the motor picks up sufficient speed. This motor is used for small power outputs in pumps, refrigerators, and many other domestic appliances.

3-36. The Universal Motor

There is a type of small motor, almost similar in construction to a D.C. series motor, which can be used in either D C or A.C. supply. That is why it is called a 'Universal Motor' The principle of its operation can be understood easily by considering a D C. series motor. Fig. 3.36(a) shows that when terminal A has a positive and terminal B a negative polarity, the motor runs in the clockwise direction. In Fig 3 36(b) the polarity is reversed, and terminal A is of negative and B of positive polarity Owing to this reversal, the polarity of the poles of the motor as well as the direction of current in the armature conductors get reversed But by applying the 'Left-hand rule' it may be seen that the direction of torque remains the same, and the motor runs in the same direction as before. When an A.C. source of supply is connected across A.B., the polarity of these terminals gets reversed every half cycle of the alternating voltage. But the direction of rotation remains the same

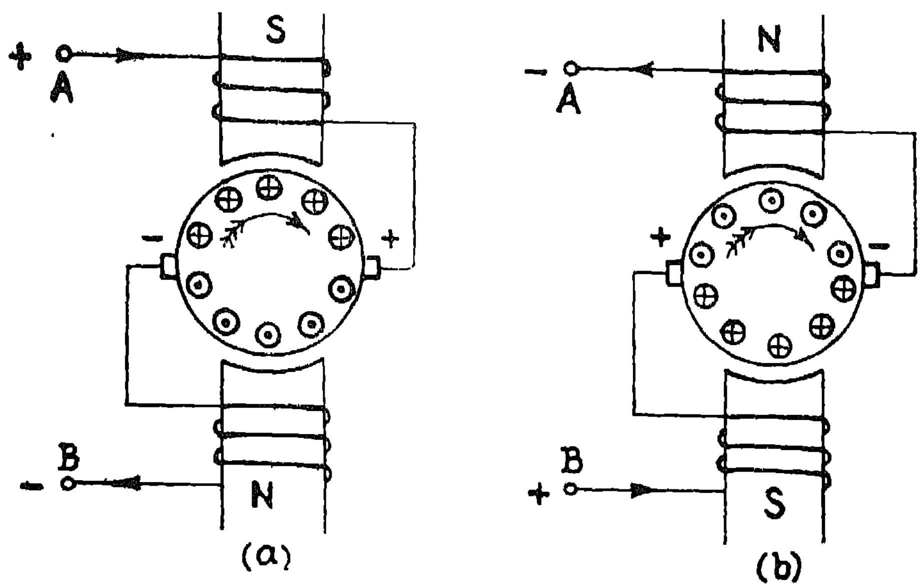


Fig. 3.36. Working Principle of the Universal Motor

The universal motors are used in

electric shavers, sewing machines, motion-picture projectors, portable drills, small grinders and some other devices requiring small power.

3·37. Synchronous Motor

The construction of a synchronous motor and that of a 3-phase alternator are identical. The stator has a 3-phase winding and is connected to a 3-phase supply This will produce a rotating magnetic field in the stator Fig 3.37 shows a two-pole motor The north and south poles of the rotating field are revolving at synchronous speed, given by Ns 120 f/P If the frequency is 50 c/s, the synchronous speed is 3000 r.p.m. Now, let the rotor be rotated by some other device and brought up to

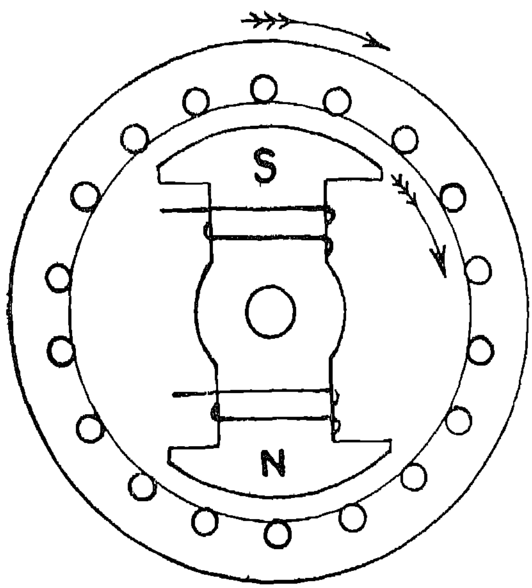


Fig. 3.37. Working Principle of the Synchronous Motor

the synchronous speed and the field current be switched on. With this condition, when the south pole of the rotor comes opposite the north pole of the stator, and the north pole opposite the south pole, the stator and rotor poles get locked together because of the force of magnetic attraction The motor now continues to run along with the stator rotating field at synchronous speed, in this locked state

Synchronous motors are used where a load is to be driven at a constant speed. This motor has another advantage in this that it is possible to vary the power factor of the current, drawn by the motor from the A.C. source, to lagging or leading. At a certain value of the field current, the power-factor becomes unity. When the field current is decreased below this value, the power factor becomes lagging, and when increased above this value, the power factor is leading. In fact, an over-excited synchronous motor without any mechanical load takes a current of 90° leading power-factor, and as such behaves like a condenser. Under this condition, the synchronous motor is called a 'Synchronous condenser'.

QUESTIONS AND EXERCISES

1 State three different kinds of effects of electric current, with an illustration in each case.

2. On what factors does the heat produced by electric current depend?

3. State Faraday's laws of electrolysis.

4. Explain the principle of current measurement by a Silver voltameter.

5. Distinguish between the wet and the dry types of primary cells

6 Explain how a primary cell developes e.m.f.

7 What are secondary cells? How do they differ from primary cells?

8. Describe a lead-acid storage battery, explaining the chemical reactions for charging and discharging conditions.

9 Show, by means of a connection diagram, how you will charge a battery from a D.C supply.

10 How will you check the battery to ascertain its charging conditions?

11. State the rules for charging a battery.

12. What is meant by the internal resistance of a battery? What does this resistance represent?

13. Describe the various parts of an alternating current generator, indicating the functions of each

14. Describe the constructional features of a D.C. generator. Explain how commutator makes it possible to obtain an unidirectional current from the machine where the voltage induced is of an alternating nature.

15 What is the basic principle of armature winding in a D.C. machine? What will determine the voltage and current outputs of a machine?

16. Explain, with diagrams, the differences between 'series', 'shunt', and 'compound' generators.

17 What is three-phase system of voltages and currents?

18 How is the A.C. ampere related to the D C. ampere? What is the r.m.s value of an A C. voltage in terms of its maximum value?

19. What do you mean by the statement that the current in a purely resistive A.C circuit is in phase with the voltage across it?

20. Explain the term 'power-factor'. What will determine the power-factor of an A.C. circuit?

21 Derive the expressions for current and power in (a) a series circuit consisting of a resistance and an inductance, (b) a series circuit containing a resistance and a capacitance, when a voltage of known frequency is applied.

22. A series circuit consists of a resistance of 10 ohms, an inductance of 76 millihenries, and a capacitance of 200 microfarads. A voltage of 110 V and of frequency 50 cycles per second is applied across the circuit. Determine the following:

(a) the current in the circuit;
(b) the voltages across (i) the resistance (ii) the inductance and (iii) the capacitance; and
(c) the power-loss in the circuit;
(d) the power-factor of the circuit.

Ans: (a) 8.6 A. (b) (i) 86 V (ii) 206 V (iii) 187 V (c) 740 W (d) 0.7825

23. A parallel circuit consists of two branches A and B, and is connect-

ed to a 220 volts, 50 cycles per second supply. Branch A has a resistance of 20 ohms in series with an inductance of 1.9 henries, and branch B a resistance of 25 ohms with a capacitance of 50 microfarads. Calculate:

(a) the currents in branches A and B;

(b) the voltage-drops across the circuit elements in both branches; and

(c) the power loss in each branch and the total power loss.
Ans: (a) 0.368A, 3.215A, (b) 7 36 V, 219 54 V, 80 37 V, 204.79 V; (c) 2.70 W, 258.4 W, 261.1W.

24 What are the relations between (a) the line- and phase-voltages and (b) the line- and phase-currents of (i) star and (ii) delta-connected three-phase circuits?

25. What is the expression for power in a three-phase circuit in terms of (a) the line voltage and line current and (b) the phase voltage and phase current?

26. Explain the principles of operation of a Transformer What is meant by 'transformation ratio'?

27 What happens in the primary winding of a transformer when the secondary winding is switched on to a load resistance?

28 Explain how a D.C. motor develops the necessary load torque when it is mechanically loaded.

29. Explain how the speed of a D C motor is varied by means of 'armature control' and 'field control'.

30 Describe, with sketches, the starter of a D. C. motor stating the function of each part.

31 Explain the principle of action of an induction motor. What is meant by the term 'slip'?

32 Describe two methods of starting an induction motor.

33 How does a universal motor work from both the D C. and A.C. supplies?

34 How does a synchronous motor run at synchronous speed?

CHAPTER 4

Measuring Instruments and Household Appliances

MEASURING INSTRUMENTS

Measuring instruments are devices used to measure the various electrical quantities like current, voltage, watts and watt-hours. The instruments should have such characteristics that when placed in the circuits where these quantities are to be measured, their insertion in the circuit must not affect the values of those quantities as they existed until their insertion

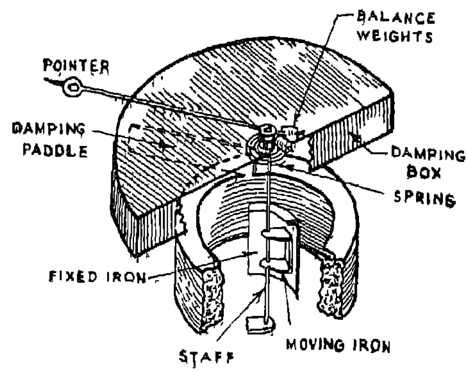


Fig. 4.1. A Moving Iron Ammeter

4-1. Ammeters

An *ammeter* measures current in a circuit, and is to be placed in series where it is to be measured A type of ammeter which can measure current in both D C and A.C. circuits is the 'moving-iron' ammeter Fig 4 1 shows the construction of a moving-iron ammeter. It consists of a coil, wound on a bobbin made of insulating material. Inside the bobbin are two strips of soft iron, placed axially and remaining nearest to each other when the instrument is not energised One of them is fixed, while the other can move The moving piece of iron is mounted on a spindle along the axis of the coil, which carries a pointer. The pointed end of the pointer moves over a graduated scale to indicate the measured quantity. The other end of the pointer extending slightly from the point of support on the spindle, carries some weights The arrangement is such that when the instrument is not energised, the pointer rests on the zero of the scale, and the downward force or gravity on the weights acts vertically through the spindle, and so has no effect on the pointer As the pointer moves from its zero position, moving the weights along with it, the vertically downward force on the weights forms a moment about the spindle of the instrument which tends to restore the pointer to its original position. This is called 'gravity control'. When a current passes through

the coil, it acts like a solenoid and the magnetic field produces a north pole at one end and a south pole at the other This field also induces magnetism of identical polarity at the two ends of the fixed- and moving-iron strips. Since like-poles repel each other, a force of repulsion is experienced by the two ends of the moving iron strip, which deflects the pointer. The restoring couple of the weights, also called 'control weights', increases with the increase of deflection of the pointer, so that the pointer comes to rest at a point where the deflecting couple (produced by the force of repulsion) is equal to the controlling couple of the weights. The controlling couple can also be produced by a spiral spring on the spindle of the moving system.

The induced magnetism in each strip of the iron is proportional to the magnetizing force, and hence to the current (I) in the coil. The force of repulsion is proportional to the product of the pole-strengths of the two strips. Since both the pole-strengths are produced by the same current, the force of repulsion or the deflecting couple will be proportional to the square of the current in the coil which may be written as

$T_D = K_d I^2$, where K_D is constant.

Since the controlling couple is proportional to the deflection θ, it may approximately be written as

$T_c = K_c \theta$, where K_c is another constant.

The pointer will be at rest when $T_D = T_c$, so that

$$K_d I^2 = K_c \theta$$

$$\text{or } \theta = \frac{K_d}{K_c} I^2 = K.I^2.$$

This shows that the deflection of the pointer will be proportional to the square of the current, which means that the distance covered by the pointer will increase rapidly with the increase of the current For example, when the current becomes double, the pointer will cover four-times the distance it covered before.

Now one will understand easily why this instrument will also work in A.C. During the positive half-cycle of the current, the deflection will be positive. During the negative half-cycle also, the deflecting torque will be proportional to $(-I)^2 = +I^2$ and the deflection will be positive. Thus it is seen that with A C. also $= KI^2$ where I is the r.m s value of the current

Another type of ammeter called the 'moving-coil' ammeter is used to measure currents in D C. circuit. The principle of its operation is similar to that of D.C. motors. Fig. 4.2 shows such an instrument. This consists of a cylindrical magnetic core surrounded by two poles of a permanent magnet, with a narrow and uniform gap between them On the core is mounted a rectangular thin aluminium-former, which carries a coil, wound with very fine insulated wire, in the air-gap between the

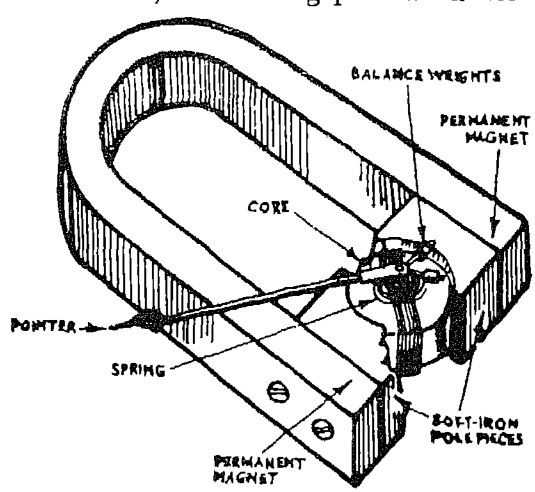


Fig. 4.2. A Moving Coil Ammeter

poles and the core The ends of the coil are connected to two control springs at the two ends of the core through which currents can be led into the coil. The spindle of the coil-assembly, mounted on two jewel-bearings, carries a pointer which can move over a graduated scale The springs always tend to bring the pointer back to its "zero" position when it is displaced from there

When a current (I) passes through the coil, it experiences a couple, due to the force induced on the two coil sides under the two poles of the permanent magnet The deflecting couple is proportional to I, or

$T_D = K_d I$

and the controlling torque provided by the spring, is proportional to the deflection θ, so that

$T_c = K_c \theta$.

When the pointer is at rest, $T_D = T_c$

and $\theta = K' I$.

That is, the deflection is proportional to the current, which means that the scale markings will be uniform This is an advantage over the moving-iron type.

Since an ammeter is to be placed in series with a circuit where the current is to be measured, the resistance of the instrument must be very small to cause a negligible voltage drop. If it is large, it will cause a large voltage drop and will reduce the current when inserted in the circuit, that is not desirable If the current to be measured in the circuit is large enough to burn the moving coil, a low resistance is connected across the instrument terminals, so as to divert most of the current through this parallel resistance, (called a 'shunt') and only a fraction of the main current is passed through the instrument coil. With this arrangement, the scale of the instrument is also modified, or *calibrated*, as it is called, to the value of the main circuit current so that, although the instrument carries a fraction of the main current, the reading always gives the value of the main current. The ranges of the current to be measured by an ammeter can be changed by adjusting the value of the shunt to suit the maximum current of the range.

4-2. Voltmeters

A voltmeter measures voltages across two points in a circuit. The moving-iron and moving-coil instruments, that are used to measure currents, are also used to measure voltages. Since a voltmeter is to measure voltage, it has to be connected in parallel across two points. There are two points to be considered for the use of these instruments as voltmeter. First, the resistance of the instruments is very small, and, if connected across two points directly, the voltage will always be sufficient to cause a current that will damage the instrument coil. Second, the current taken by instrument must be very small so as not to change or affect the normal current distribution in the circuit, as this will also change the voltage to be measured. These two problems are solved by connecting high resistance in series with the instrument, so that the current taken by the instrument is small and corresponds to a value that will give full-scale deflection when the instrument is used as an ammeter without shunt. The value of this series resistance, called a 'multiplier resistance', is adjusted to enable the same instrument to measure voltages of various ranges in various circuits.

4-3 Wattmeters

A wattmeter measures power in a circuit A common type of this instrument is a 'Dynamometer wattmeter'. The principle it works on is similar to that of a 'moving coil' instrument The instrument has two fixed coils instead of the two poles of a permanent magnet Fig. 4 3 shows a Dynamometer type of wattmeter. The two fixed coils are connected in series in the circuit where the power is to be measured. Since they carry the current of the circuit, the two fixed coils are also called *current coils* The other coil is the moving coil and has a high resistance in series This coil is connected across the two terminals of the circuit in parallel, so that it has the voltage of the circuit across it at that point. Hence the moving coil is also called the *potential coil.*

The moving coil, carrying a current proportional to the circuit-voltage (V), is acted upon by a deflecting couple as it moves in the magnetic field, produced by the fixed coil and proportional to the current (I) in the circuit. This means that the deflecting couple is proportional to the product of circuit voltage and circuit current or the power, and may be written as

$$T_D \quad H_W VI$$

The controlling torque is provided by spring, and may be written as

$$T_C = K_C \theta$$

When the pointer is at rest, $T_D = T_c$, and

$$\theta = K. VI.$$

This shows that the instrument deflection θ is directly proportional to the power (VI), and the scale of the instrument will be uniform, as in the case of a moving coil instrument

When used in the A C circuit, this wattmeter will read the average value of the instantaneous product of voltage and current, which is the power, and given by VI cos ϕ, cos ϕ being the power factor of the circuit.

There is another type of wattmeter called the 'induction type' as shown in fig 4 4 This can be used only in A.C circuits. It consists of a copper or aluminimum disc which can rotate freely between the poles of two A C electromagnets The alternating flux of each

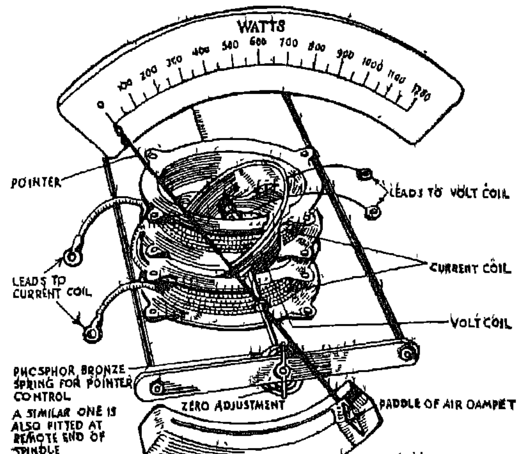


Fig. 4.3. A Dynamometer Wattmeter

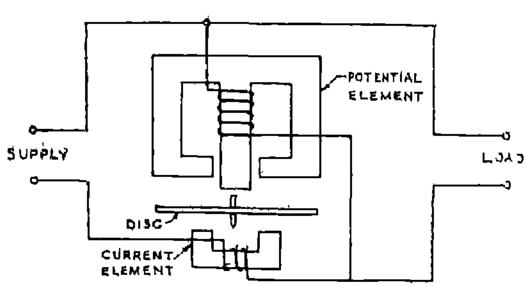


Fig. 4.4. An Induction Type Wattmeter

magnet induces voltage in the region of disc under the poles This voltage produces circulating current in the disc that is called "eddy current." The flux of one coil linking the current of the other coil will produce torque on the disc To make the resultant torque move the disc, it is necessary to have a phase difference between the currents flowing in the two coils This is arranged by making the power factors of the circuits of the two coils different. For measuring power one coil (the current coil) is placed in series, and the other coil (the potential coil) in parallel With this connection, the resultant torque will be proportional to the power in the circuit Since an induction-type wattmeter has spiral springs for restoring the pointer, the controlling torque is proportional to the deflection. Therefore, as for the dynamometer type of wattmeter, the deflection is proportional to the power in the circuit.

4-4. Energymeters

The instrument used to measure energy in a circuit over a certain period of time is called energymeter. Fig. 4.5 shows an 'induction type' energymeter. This instrument is exactly similar to the induction type wattmeter, except that there is no control-spring, but instead of this, there is a *brake-magnet*, which is a permanent magnet, mounted so that the main disc of the instrument can rotate freely between the two poles of this magnet If the disc rotates at a speed of N revolutions per second the e.m.f induced by the flux of the permanent magnet in the disc will be proportional to N Hence the eddy-current also will be proportional to N because the resistance of the eddy-current path is a constant Applying Lenz's Law to this case, it is seen that the torque produced by the eddy-current with the flux of the brake magnet must act in the opposite direction to prevent the rotation of the disc and that is how it *brakes* the disc The magnitude of this torque will be proportional to the eddy current, the flux being constant Therefore, the braking torque will be proportional to n, and may be expressed as $T_B = K_1 n$, where K_1 is a constant. The deflecting torque which is rotating the disc is proportional to the power P in the circuit, and may be expressed as $T_D = K_2 P$, where K_2 is a constant. The disc runs at a constant speed when there is no accelerating torque acting on the disc, and that happens when $T_D = T_B$. Therefore, at constant speed

$$n = \frac{K_2}{K_1} p = K_3 p, \text{ where } K_3 \text{ is a constant.}$$

Under this condition the speed of the disc is proportional to the power in the circuit

Let the power P be in kilowatts and the speed N be in r.p.m Then in one minute, the disc makes N revolutions and the energy consumed in the circuit in one minute will be

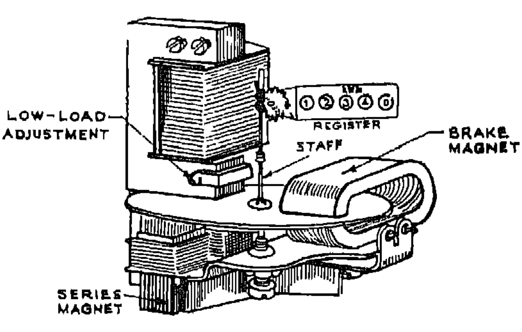


Fig. 4.5. An Induction Type Energymeter

Energy = Power × time = PN K_w — min.

$$= \frac{PN}{60} K_w h.$$

Therefore, $\frac{PN}{60} K_w h$ corresponds to N revolutions

or 1 Kwh will correspond to $\frac{60N}{PN} = \frac{60}{P}$ revolutions.

So, the number of revolutions made by the disc of the energymeter is a measure of the energy consumed. In an actual energymeter there is a train of gears with a transmission ratio $\frac{1}{10}$ in each step, with a dial for every step. This makes it possible to measure energy in steps of $\frac{1}{10}$, 1, 10, 100, 1000 and 10000 of a unit (Kwh).

A common type of D.C. energymeter is the *mercury energymeter*, as shown in fig. 4.6. In this case also, a copper disc rotates under the poles of two sets of permanent magnets. The chamber in which the disc rotates is made of two round brass-plates placed one above the other and separated by a fibre ring. The vertical centre-line of the chamber is in line with the axis of the disc's spindle The chamber is filled with mercury. The two sets of the pole pieces of the permanent magnets are forced into the brass-plates, and are placed on the two sides of the spindle in a position diametrically opposite to each other. The current of the circuit is led into the meter through a contact placed on the fibre-ring at the periphery of the chamber and it reaches very near to the disc with a very small gap filled with mercury. The current, comes out of the disc through a screw at the lower support of the spindle. When a current

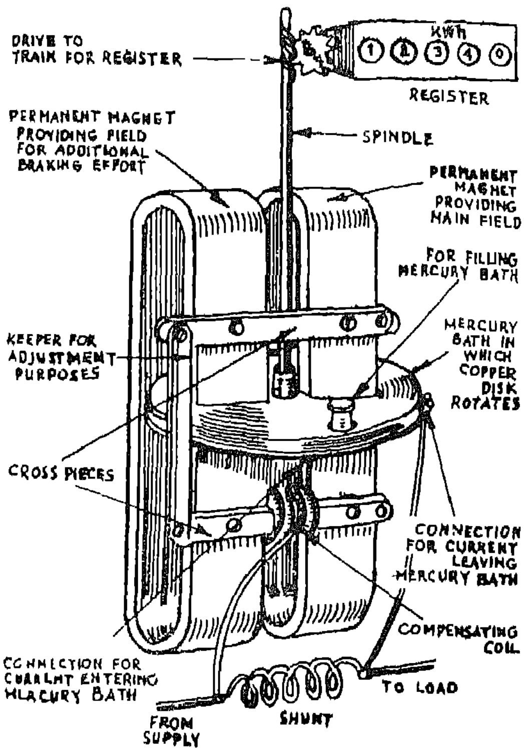


Fig. 4.6. A Mercury Energymeter

flows through the contact, the mercury and the disc, the radial portion of the disc, which is under one set of permanent magnet, experiences a force (according to the Left-hand Rule) and the disc starts rotating. The developed torque will be proportional to the current (I). As the disc starts rotating, a braking torque will be acting on the disc due to the other set of permanent magnets. As shown earlier, the braking torque will be proportional to the speed (N). Therefore, when the disc is rotating at a constant speed, these two torques will be equal and the speed will be proportional to the current. This can be written thus:

$$N = K\ I.$$

If the disc makes N revolutions, say, in one hour, then N revolutions will be

proportional to I ampere-hours Therefore, this instrument is known as an 'Ampere-hour Meter'. If the voltage of the circuit is known, then the ampere-hours can be multiplied by this voltage to give watt-hours, which again can be calibrated in terms of Kwhs Although the instrument measures ampere-hours, the train of dials can be graduated in Kwh and their multiples

The energymeters are also known as 'House-service Meters', because the supply authorities install this meter, for billing purposes, in every house to which electrical energy is supplied.

HOUSEHOLD APPLIANCES

Most household heating appliances make use of the principle of obtaining heat by passing current through resistance coils. Each of these appliances use resistance elements. The differences in the construction of the appliances are the location, utilisation and control of temperature of these elements

4-5. The Thermostat

A thermostat controls the operation of most of the heating appliances by acting as a switch. It consists of a *bimetal strip* which is placed in that region of the appliance where heat is produced, and is connected to one terminal The other terminal is connected to a fixed contact point. The bimetal-strip is made by joining two strips of different metals, having different coefficient of linear expansion, say, brass and iron. Fig. 4.7 shows that arrangement of the device. When the temperature is within the safe value, the terminals remain closed through the contact point and the bimetal strip If the temperature rises above the safe limit, the brass part of the bimetal strip expands more than the iron part and the strip bends disconnecting the terminals at the contact point. When the strip cools, it becomes straight again and closes the contact.

This device may also be arranged in such a manner that, under normal operation, the contact will be open, and at high temperature the contact will be closed by the bimetal strip.

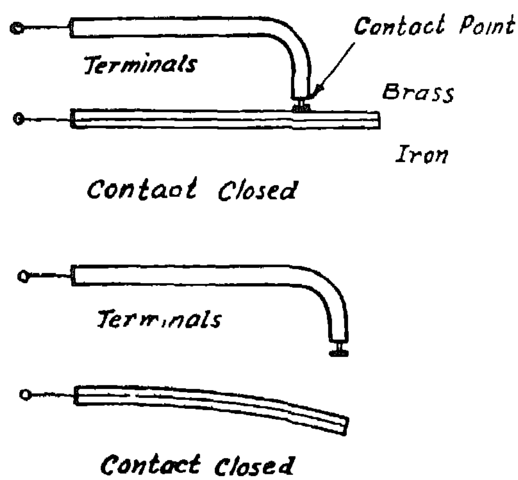


Fig. 4.7. A Bimetal Thermostat

4-6. The Toaster

The heating elements of a Bread-toaster are made of flat ribbon-shaped wires wound on sheets of mica. These elements are mounted on the toaster frame Fig. 4 8(a) shows the electrical circuit diagram of a common toaster The heating elements are connected in parallel and may have a power rating of approximately 1000 watts The main switch is closed when the toaster-carriage is pushed down.

Many toasters have automatic devices

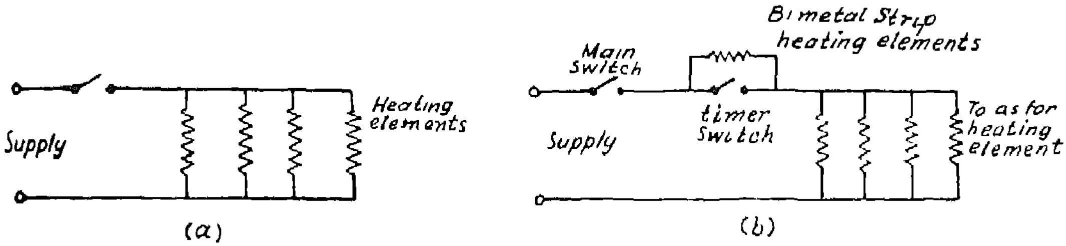


Fig. 4.8. Electrical Circuit Diagrams of Electric Toaster

controlling the toasting and the bread-raising mechanism, when the toasting is complete. Fig. 4.8(b) shows the electrical circuit of such a control arrangement. A bimetal strip, wrapped by a heating element, controls a timer switch, which in turn controls the main switch. When the toaster is switched on, current passes through the bimetal-strip heating element. This heats the strip and it begins to bend. After bending to a certain extent, the strip pushes the timer switch to the 'on' position which short-circuits the bimetal strip heating element and no current flows through it. The bimetal strip now cools down, and starts bending in the opposite direction and, after some time, pushes another lever, which releases the spring-driven toaster carriage upwards. This action also puts the main switch and the timer switch to the 'off' position and thus completes the toasting.

4-7. The Clothes Iron

The clothes iron is used to press the garments and other clothes by the heat, produced in some resistance elements inside the iron The ordinary irons do not possess any temperature control device, and they give heat at a certain constant rate depending upon the wattage of the heating elements. Such an iron may attain a very high temperature if kept on to the supply for some time without using it

Another type of iron has two bimetal strips to control its operation and protect it from excess of current. Fig. 4 9(a) shows the construction of such an Iron In fig. 4 9(b) is shown the working principle of the bimetal-strip operation. The thermostat is connected in series with the heating element. When the iron is switched on to the supply the thermostat contacts are closed and the circuit to the heating element is complete As the Iron gets heated owing to the current flowing through the heating elements, the bimetal strip is also heated and it bends to open the circuit. When the iron has cooled down to a certain temperature, the thermostat contacts close again. This action is repeated during the operation of the iron and the temperature of the iron is maintained more or less to a constant value during its use. The temperature at which the iron is to work can be set by a *heat-regulator knob*. The heat-regulator acts on a lever, which can increase or decrease pressure between the thermostat contacts by screwing or unscrewing the knob. As the pressure increases, the

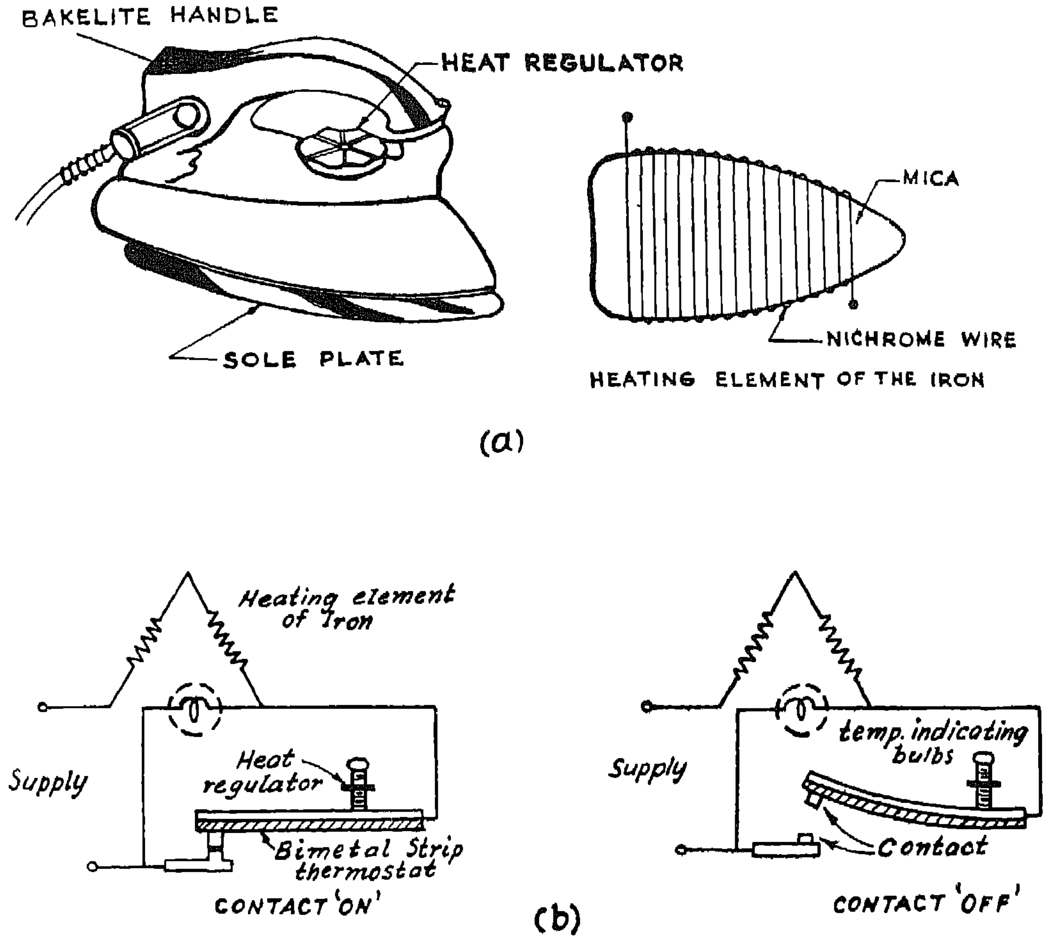


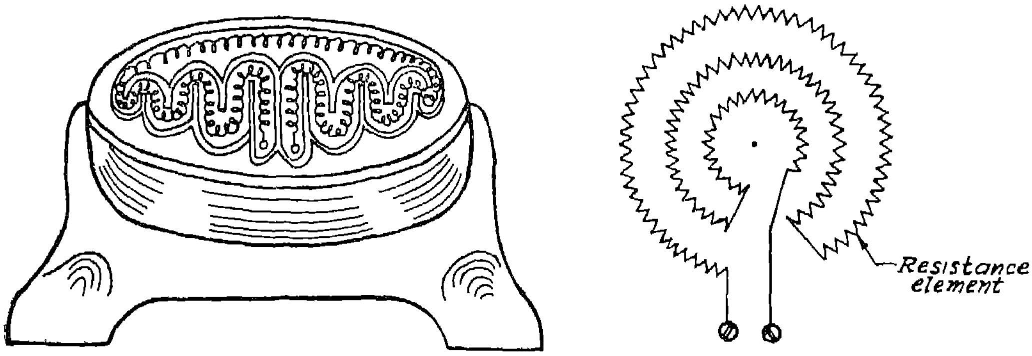
Fig 4. 9. **Working Principle of an Electric Iron**

temperature of the iron must increase before the contacts can be opened. In many irons a bulb is connected, as shown in the figure, to indicate that the iron has attained its maximum temperature. When the contacts separate the voltage of the supply appears across the bulb and it glows.

4-8. The Electric Cooking Range

In its simplest form this device is very commonly known as 'Electric Heater'. It consists of a porcelain body with circular groves where the resistance coil can be placed. This porcelain body, as shown in fig. 4 10(a), electrically insulates the resistance element, and is supported by a metallic body at the bottom. The terminals are on one side of this body and a pair of connecting wires are brought out through holes of small porcelain tubes. On the top of the porcelain body is an iron-grid, which protects the porcelain as well as prevents the utensils used for cooking from coming

into contact with the porcelain and the heating elements. The amount of heat that the heater can give out depends on the resistance of the element, and is given in terms of wattage of the heater. The usual sizes are 500 W, 750 W, 1000 W and 1500 W. Fig 4 10(b) shows the connections of the heating element. The wire is insulated from the tube by a substance akin to magnesium oxide The special property of this substance is that though it is an electrical insulater, its thermal or heat-conductivity is high. Hence the heat developed by the elements can come out even though the elements are completely covered This

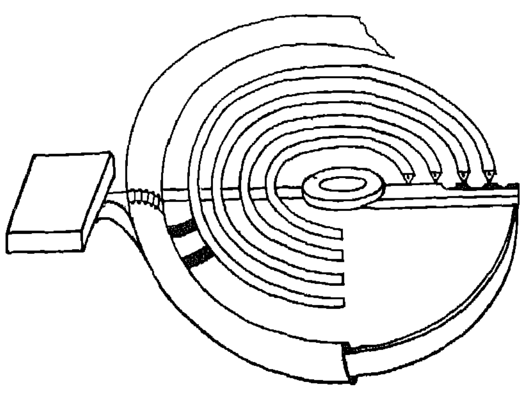


(a) (b)

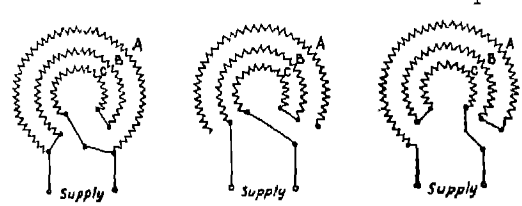
Fig. 4.10. An Electric Heater

The construction of a modern *Electric Range* is shown in fig 4 11(a) The top heating element consists of a resistance wire placed within a metal tube construction increases the life of the element, and also ensures safe operation in that there is practically no possibility of an operator getting electric "shock".

The temperature of the top element is controlled by controlling the current in it by a *heat selector switch*. This switch connects the heating elements in various ways to the supply. Fig 4.11(b) shows that B and C elements are always in series and the total resistance is equal



(a)



(b)

Fig. 4.11. A Cooking Range

to that of A. In the "high" position the two equal resistances are in parallel and gives the maximum heat output. In the "medium" position only one Resistance (B and C) is in circuit In the "low" position all resistances (A, B and C) are in series, giving the lowest possible current and the lowest heat.

4-9. Electric Bell

Electric bells are used as 'calling bell' in houses where a switch is placed at the entrance They are used in offices, and in industry for indicating alarm Fig 4 12 shows an electric bell with its various parts. When the switch is put on, a current flows through the electro-magnet, via the contact-point and contact strip. This will energise the electro-magnet and the armature will be attracted by the core of the electro-magnet This will result in the separation of the contact strip from the contact point, and the current in the circuit will be interrupted. Without any current in the electro-magnet, it loses its magnetism and the armature comes back to its original position because of the pull of the spring As soon as this happens, the contact strip touches the contact point and the circuit becomes closed again, and the whole cycle of operation is repeated. This shows that the armature will move to and fro, thereby moving the clapper on the gong, and the bell will ring continuously so long as the switch is kept on

In D.C. circuits, the core of the electro-magnet may be a plain soft iron cylinder. In A C. circuits, a slot is cut at the end of the core, and a *copper shading-ring* is put on in slot round the

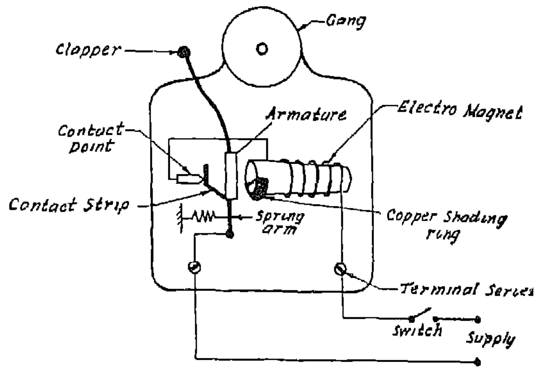


Fig. 4.12. An Electric Bell

outer surface. Without this shading ring the core will not be able to pull the armature.

4-10. Electric Fan

An electric fan is nothing more than an electric motor, to which are attached two or three blades, so that when the fan rotates, it can displace or blow air A D.C fan is a D.C. series motor, with the usual poles A C. fans are single-phase induction motors Fig 4.13 shows a shaded-pole type 1-phase induction motor In this case two out-of-phase fluxes are produced under the main-pole and under the shaded-pole The induced current due to one, with the flux of the other pole, produces the necessary torque and the motor rotates with a slip corresponding to its synchronous speed. Since these motors are usually made for four poles and the frequency is 50 c/s, the speed of the motor is little less than 1500 r.p.m.

The speed of the fans are controlled by *regulators*. A regulator has a number of resistance-steps in series, and is connected to the fan-motor in series with the supply The applied voltage to

the motor can be varied by varying these resistances, in steps, and so the speed can be controlled.

Afterwards it flows again to the evaporator coils, and the cycle of operation continues as long as necessary.

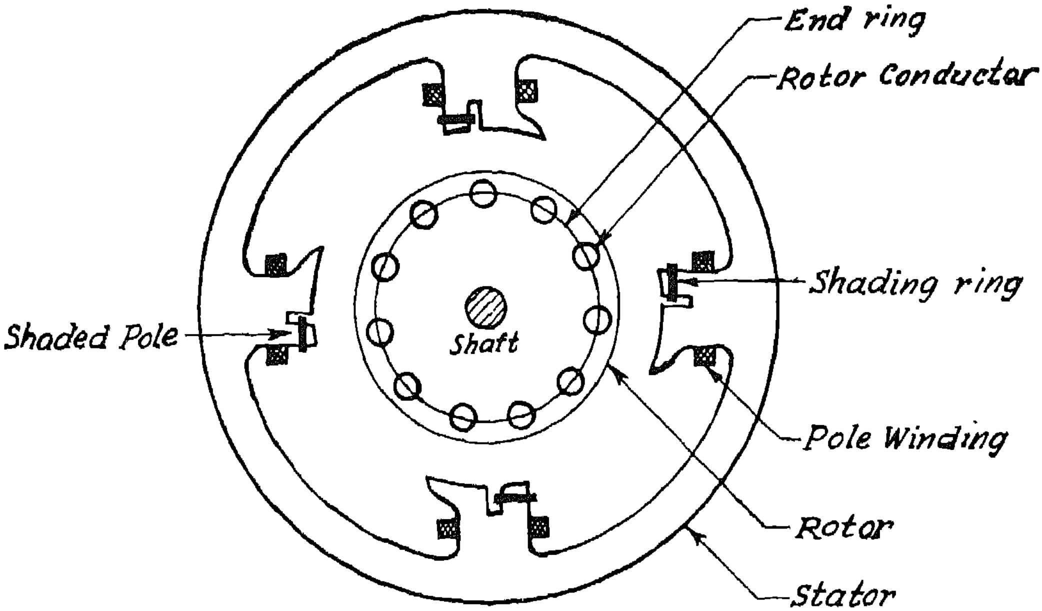


Fig. 4.13. A Single-phase Shaded-pole type Electric Fan

4-11. Refrigeration and Air-conditioning

The basic principle of operation of the *refrigerators* and *air-conditioners* is that all liquids absorb heat, called the latent-heat of evaporation, when they evaporate. In these cooling appliances, a liquid known as the "refrigerant" is circulated through tubes made of thin metal The tubes are shaped like coils which are called *evaporator coils* The substance used as a refrigerant has a very low boiling point, which means that the substance evaporates at a very low temperature Therefore the evaporator coils are cooled and they absorb moisture from the surrounding air. The evaporated refrigerant is then taken out of the coils and passed through a compressor and a condenser, resulting in its cooling and changing back to the liquid state.

4-12. The Refrigerator

Fig 4.14 shows the important parts of an electric refrigerator. The refri-

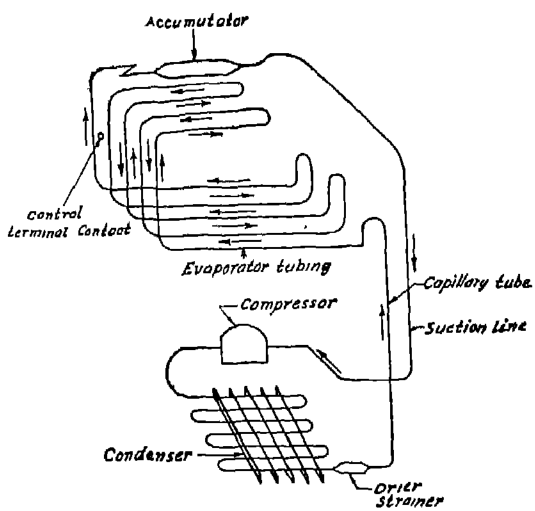


Fig. 4.14. Working Principle of a Refrigerator

gerant commonly used is called 'freon'. The evaporator tubes are located in the upper part to the cabinet of the refrigerator. The compressor is driven by a 1-phase induction motor There is a thermostat controller near the tubes When the temperature inside the cabinet rises above a certain minimum set temperature, the thermostat closes a contact and the motor drives the compressor. The compressor pumps the evaporated 'freon' out of the tubes and cools it and brings it to the liquid form. The liquid freon is then forced back into the evaporator coils where it evaporates again thereby taking away the heat from the freezer compartment of the refrigerator. In this way the cycle repeats itself so long as the refrigerator is in operation. When the temperature inside falls below a certain value the thermostat control opens the switch of the compressor motor. The refrigerator remains in this condition until the freezer compartment absorbs enough heat This heat is absorbed from outside through the refrigerator body and other leakage paths so much so that the temperature inside rises sufficiently to operate the thermostat which closes the contacts. This results in the starting of the motor again and repeating the cycle of actions.

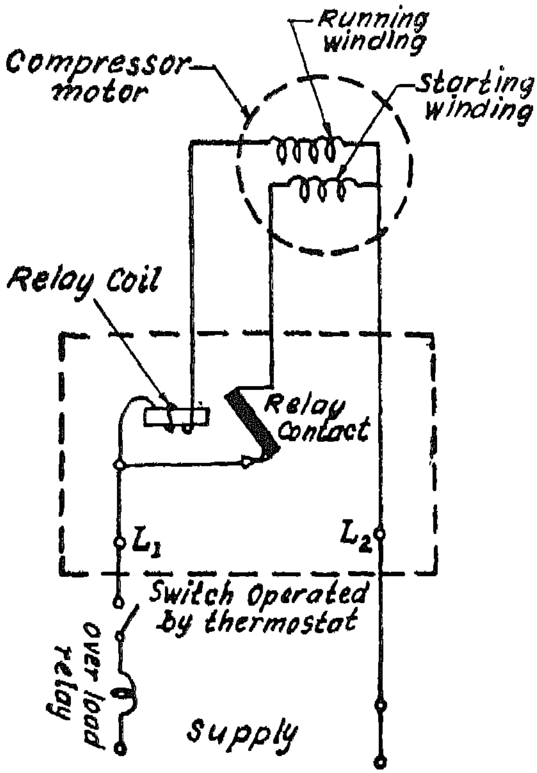


Fig. 4.15. Automatic Control Circuit of a Refrigerator

The compressor motor has a starting —and a running—winding A motor starting relay cuts in and out the starting winding as shown in fig. 4.15. When the refrigerator needs cooling the supply is connected to L_1 and L_2 terminals through the switch controlled by thermostat A current now flows through the running winding and the relay coil. The relay coil gets energised and closes its contacts, thereby allowing currents to flow through the starting winding also. The motor starts and gradually speeds up. After it has gathered sufficient speed the current in the running winding decreases and the relay current becomes insufficient to keep its contact closed. Hence the current in the starting winding stops flowing and the motor runs with only the running winding connected to the supply.

If the motor becomes over-loaded, its speed falls, resulting in an increase in the current drawn from the supply. This excess current heats the bimetallic

strip of the over-load relay and the strip bends to push a lever, disconnecting the supply from the motor windings

4.13. *Air-Conditioner*

An air-conditioner cools, dehumidifies, cleans, and circulates the air within a certain space. This is used in dwelling houses, offices, and factories, and is nothing more than a refrigeration unit Figure 4 16 shows the main parts of an air-conditioner Air from a room is drawn through a filter which removes dirt, dust and other suspended particles from it. It is then passed through an evaporator coil cooling assembly. The coils are cooled by the evaporation of the refrigerant as for a refrigerator The cooling capacity of an air-conditioner may be given in terms of heat units like *kilocalories*. One kilocalorie represents the amount of heat required to raise the temperature of one kilogram of water through one degree centigrade The kilocalories rating of an air-conditioner gives one an idea of how much heated air it will remove from a room to the outside atmosphere during a given period of time, usually one hour The greater this rating, the larger will be the space that the air-conditioner will cool under any given temperature condition

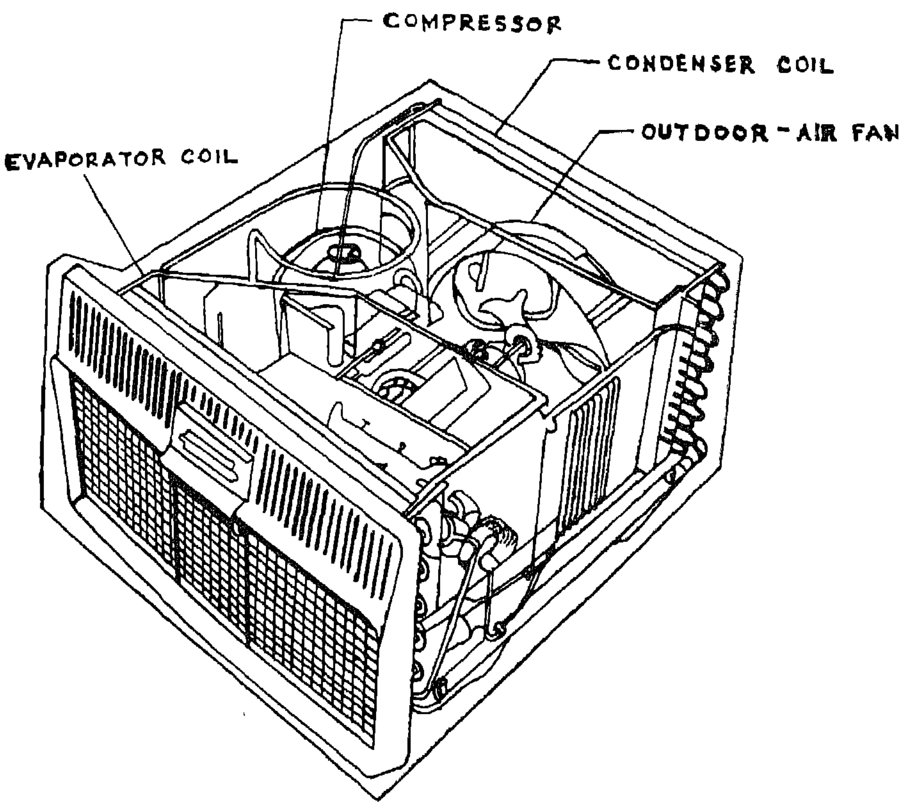


Fig. 4.16. An Air-conditioner

QUESTIONS AND EXERCISES

1. Explain with sketches the working principle of (a) a moving-iron ammeter (b) an induction type wattmeter.

2. Explain why (i) an ammeter should not have large resistance and (ii) a voltmeter should not have low resistance.

3. How can you use a moving-iron or a moving-coil instrument either as an ammeter or a voltmeter? How can their working ranges be extended?

4. Describe briefly a dynamometer type of wattmeter

5. Name the types of instruments that can be used on both D C. and A.C. supplies?

6. How does an energymeter record kilowatt hours consumed by an user of electricity in an A C. system?

7. Describe constructional features of a D C energymeter Explain the principle of its operation

8. What is a thermostat? How does it work as a switch when the temperature in an apparatus changes?

9. Describe with circuit-diagrams
   (a) a bread toaster,
   (b) an electric iron for pressing clothes,
   (c) a cooking range

10. Show, by means of a diagram, how an electric bell works with D C. supply. What modification is necessary to make the bell work on A C supplies also?

11. Explain the principles on which an A C. fan works.

12. Describe, with diagram, the principle of operation of (i) a refrigerator and (ii) an air-conditioner How does the automatic switch controls the compressor motor?

CHAPTER 5

Indoor Wiring and Installations

With the progress of industrialization, the living standards of people are improving day by day. The number of people or families using electricity at home also increases, and it is usual to call this increase, an increase in the consumption of electrical energy per person or per head.

5·1. Indoor Wiring

The indoor wiring system brings electrical energy into our homes, offices and other indoor working establishments The system also distributes this energy to various points inside the house Several different components and wiring devices make up the indoor wiring system They are installed and connected according to the rules and codes of practice laid down by the Indian Standards Institution.

Since the consumption in the domestic and other indoor establishments is small compared with that in industry, electricity is supplied at the low voltage of 230 volts (rated), 1-phase. In India electricity is supplied to houses at this voltage, whereas in the United States of America it is at 110 Volts. A lower voltage might even be preferable to reduce accidental electric shocks to people inside homes, but certain difficulties in the size, volume and design of the wiring devices and domestic appliances

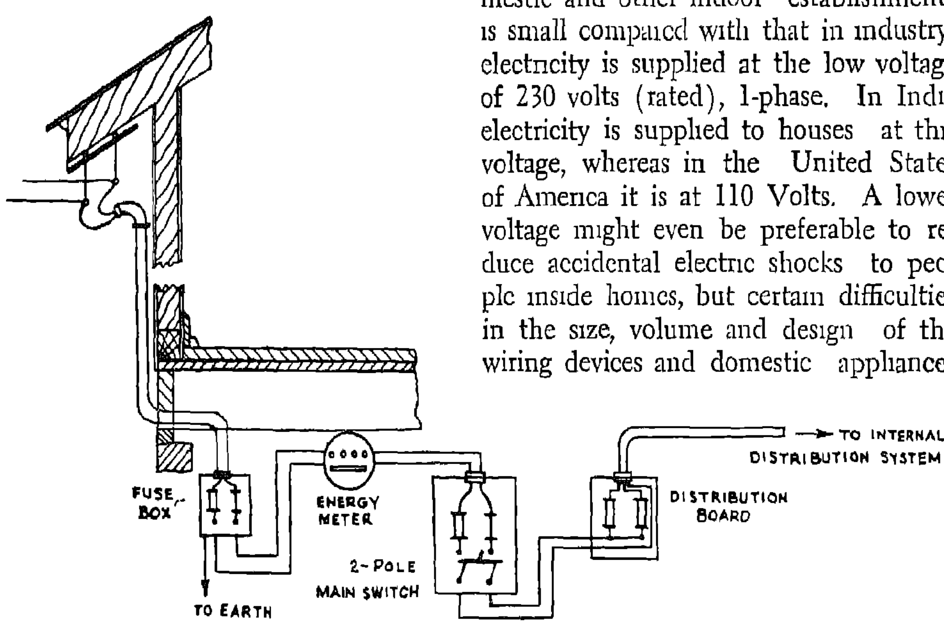


Fig. 5.1. Overhead Service Main Connection

limit the supply voltage to about 110 volts From the distributors controlled by the supply authority, one 'phase' or 'live' wire and one neutral wire are brought into the premises of a consumer through the service main This may come in the form of an overhead connection or by an underground cable, as shown in fig. 5.1. Preventive measures against accidents involving life and property must be taken, as the electrical lines are brought into and distributed inside the house. The most important of them is the provision of a 'fuse' The fuse is a piece of thin wire of silver gilted copper. When an abnormally high current passes through it, the heat developed in the fuse-wire is sufficient to melt it, and thus the circuit in which it is placed gets disconnected The fusing current depends on the size and the meterial of the fuse-wire. Fuse-wires are made for current-ranges of 2 amps to 100 amps. Various types of fuses will be described later in this chapter A fuse is always placed on the phase or live wire, and not on the neutral

A fuse, called the 'aerial fuse', is placed on the wire connecting the phase-wire of the service main at the pole of the distributor. Fig. 5 2 shows various parts and devices in the consumer's house at the point where the service main enters the consumer's permises. The incoming cable enters the cable-box, from where the live wire (L) goes through a cut-out or fuse, and the neutral wire (N) directly, to the incoming terminals of the energymeter From the energymeter two terminals go out to the *main switch*. There is a fuse on the live wire inside the main switch From the main-switch, the two wires go to a *distribution* or *fuse-board*, from where pairs of one live and one neutral wire are distributed to the various parts of the house. The live wire of each pair passes

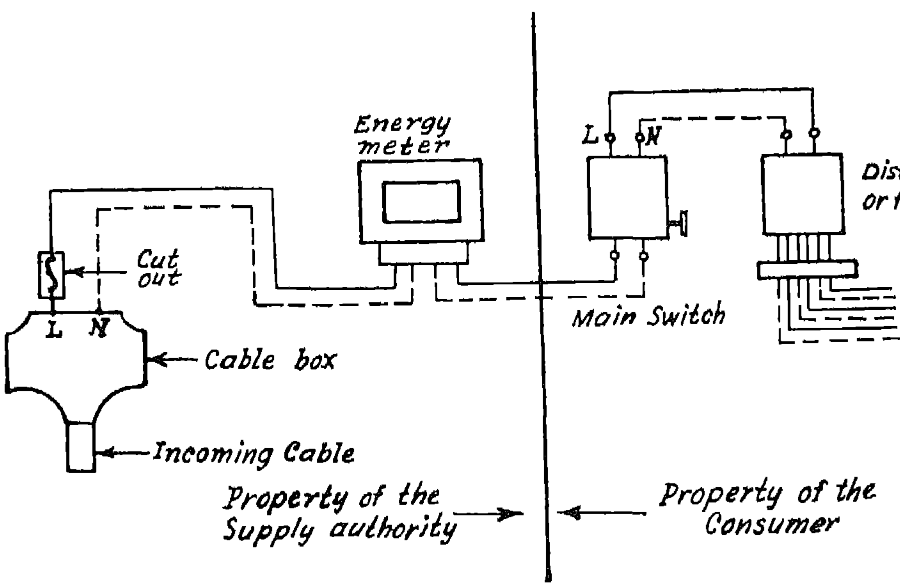


Fig. 5.2 Meter-box in the Consumer's Premises

through a fuse in the fuse-board The cut-out and the energymeter which are controlled by the supply authority, should be placed in an accessible position in the consumer's premises, so that it may not in any way be difficult for persons authorised by the supply organisation to replace the fuse or read the energymeter when such occasions arise The main switch, fuse-board and energymeter (generally called house-service meter) are all housed in a wooden enclosure called switch board.

5-2. General Requirements

With regard to wiring in the premises of the consumers, there are certain general requirements that must be fulfilled. All installations must conform to the provisions of Indian Electricity Rules, 1956. All materials used in the installation should be of standard quality as laid down by the Indian Standards Specifications (ISS). The work should be carried out under the direct supervision of a person holding a certificate of competency issued by the State Government.

The general lay-out of the wiring, as shown in fig. 5.3, should be such that 'power' and 'heating' sub-circuits are kept separate and distinct from the 'lighting' and 'fan' sub-circuits. Pumps, heaters and other household electrical appliances are usually connected to a 'power' and 'heating' sub-circuit while lights, fans and other similar loads, having a capacity not exceeding 100 watts, are mostly connected to a 'lighting' and 'fan' sub-circuit A sub-circuit means a branch of the main circuit, to which the incoming supply lines are connected. There are 'main' and 'branch' distribution boards in the distribution system of the premises The power first enters a main distribution board, and some main circuits connect them to a number of branch distribution boards. All runs of wiring (actual route of the wires in the house) and the exact position of all 'points' (where the loads are connected) and switch boxes are marked

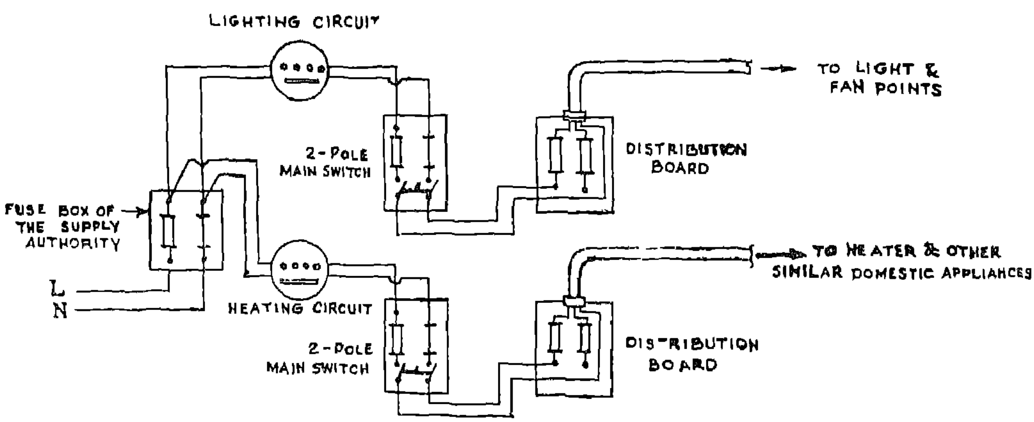


Fig. 5.3. General Lay-out of a Wiring Scheme

in advance on the plan of the building or in the building itself, and approval of the engineer in charge or of the owner is obtained before the beginning of actual work. The minimum cross-section of wires to be used for sub-circuit wiring is 1.00 mm^2 (sq.mm) copper, and 1.50 mm^2 aluminium, and for power circuits 1.50 mm^2 copper and 2.50 mm^2 aluminium. The minimum cross-section of wire of flexible chord is 0 40 mm^2.

All standard copper conductors, having a cross-sectional area greater than 6 75 mm^2, are provided with 'soldered' terminals or lugs at their ends. This is necessary to have the current properly distributed in all the strands of the wire

To estimate the current to be carried by any conductor, incandescent lamps are rated at 60 watts, unless otherwise specified. Ceiling fans, table fans and ordinary socket-outlet points are rated at 60 watts, fluorescent lamps at 40 watts, and power socket-outlet points at 1000 watts, unless actual values are known or specified.

All joints in conductors, necessary for branching out wires at intermediate positions between 'points' are made by means of mechanical *connectors*, placed in *joint-boxes*. A connector is a mechanical clamp inside an insulating material, usually porcelain, which connects the ends of wires together, as shown in Fig. 5 4 A joint box can be eliminated by using the *looping-back* system. In this system, the required branch of the conductor or wire is taken out from the

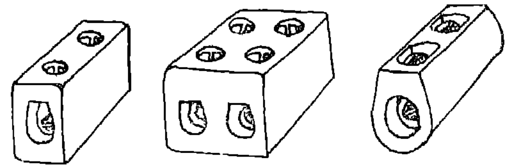


Fig. 5.4. Porcelain Connectors

nearest available 'point', where the particular wire has terminated This may also be obtained from the nearest switchboard No bare or twist-joints are made at intermediate points in the through run of wires between two 'points' If any joining becomes unavoidable, such joints should be made through proper cut-outs and junction boxes or joint boxes.

5-3. Main Switches and Switch Boards

All main switches are of metal-clad enclosed pattern or of any insulated enclosed pattern which are fixed at close proximity to the point of entry of supply. Switch boards are never mounted on a damp surface or very near to gas-stoves or sinks, in bathrooms, in lavatories or toilets, or in kitchens. For small installations of 250V supply, the switch board is usually made of teakwood, which is properly seasoned and coated with varnish. Large switchboards of 400V 3-phase supply, are accommodated in steel-framed boxes or teakwood boxes, with proper access and clearances. Fig. 5.5 shows various types of switches and switch boards A two-pole switch for one live and one neutral wire, contains circuit isolating or disconnecting arrangement on both the wires, together with a fuse on the live wire circuit and a *link* on the neutral.

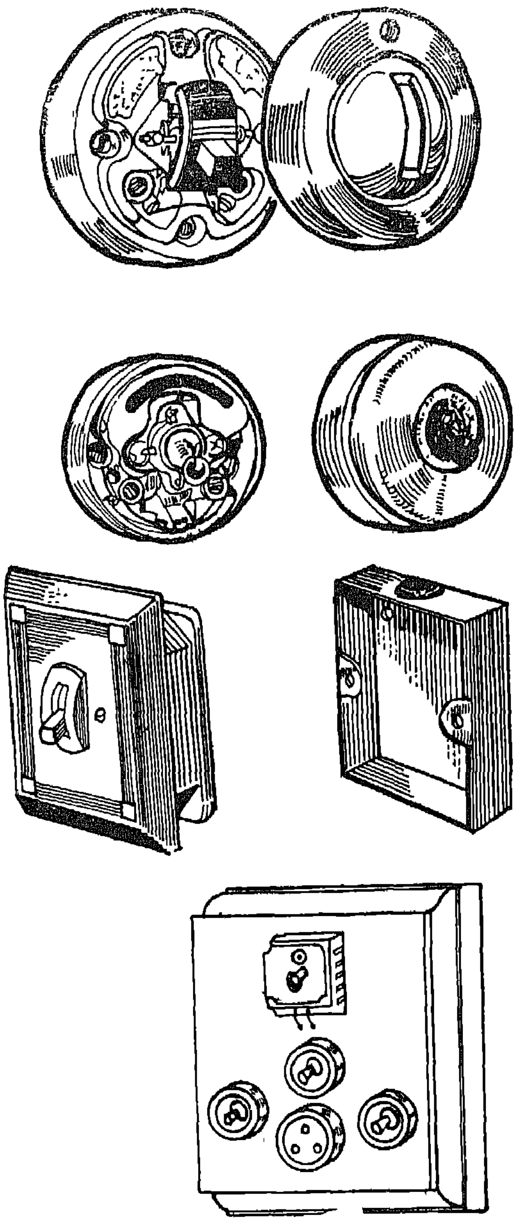


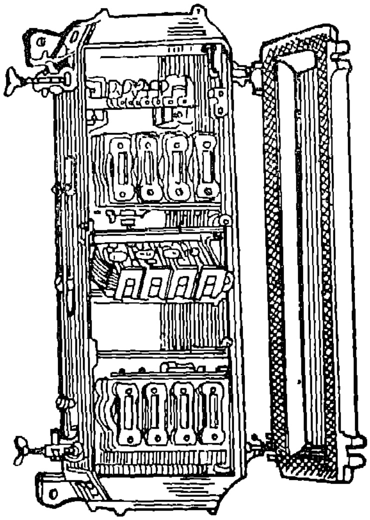
Fig. 5.5. **Switches and Switch Board**

5-4. Main and Branch Distribution Boards

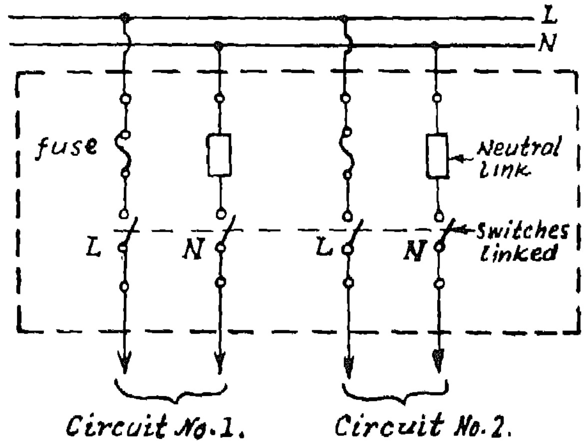
Fig. 5.6(a) shows the 'main' and 'branch' distribution boards. A main distribution board is provided with a switch on each pole of each circuit, a fuse on the phase or live conductor and a link (a metallic strip connection) on the neutral or earthed conductor of each circuit are also provided. The switches must be linked (operate together) as shown in fig. 5.6(b). Branch distribution boards are provided with a fuse on the live conductor of each circuit, and the neutral conductor is connected to a common link, which should be capable of being disconnected for testing purposes at the time of investigating the causes of defects in the circuit. Usually, one spare circuit of the same capacity is provided on each branch distribution board. Lights and fans may be wired on a common circuit. Such sub-circuits do not have more than a total of ten points of lights, fans and socket outlets. The load of such circuits is restricted to 800 watts. As regards power circuits the outlet will be provided according to the load for these circuits, but in no case will there be more than two outlets on each circuit, restricting the power drawn to 2000 wattts.

The distribution boards are located as near as possible to the centre of the load that they are intended to control, and placed on the wall in an accessible position for the replacement of the fuses. They are usually of the *metal-clad* type.

In wiring a branch distribution board, the total load of the consuming devices is divided, as far as possible, evenly among the number of ways of the board, leaving the spare circuit for future extension. All connections between pieces of apparatus or between apparatus and terminals on a board are neatly arranged in a definite sequence, following the arrangements of the apparatus, avoiding unnecessary crossings.



(a)



(b)

Fig. 5.6. Distribution Board

The fuse is mounted on a porcelain carrier for its support, as shown in Fig. 5.7 A fuse-carrier is never to be fitted with a *fuse-element* (fuse wire) larger than one for which the carrier is provided. The current-rating of a fuse should not exceed the current rating of the smallest cable in the circuit protected by the fuse. Every fuse has on its own case or cover, or in an adjacent conspicuous position, a clear and indelible indication of its appropriate current rating, that is, the circuits in which it can be used for protection

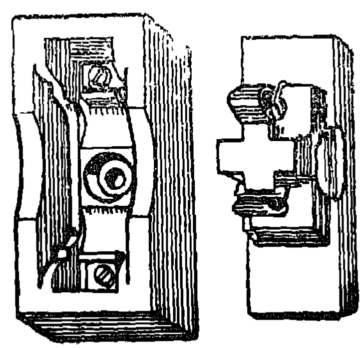


Fig. 5.7. Fuse-holder and Carrier

5·5. Passing of Wires through Walls and Floors

Care is taken to see that wires pass very freely through protective asbestos or galvanised steel pipes, which are placed in the holes on the wall through which the wires are to pass, and that the wires pass through straight withou any twist or cross in wires, on either side of such holes. The ends of the pipes

or conduits are neatly bushed with porcelain, wood or other insulating material. Insulated conductors, while passing through the floors, are protected against any mechanical injury by means of steel conduits

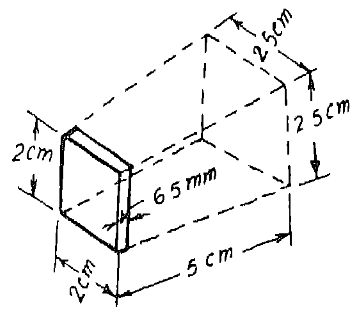


Fig. 5.8. A Wooden Plug

5-6. Fixing to Walls and Ceilings

The supports of the wires must be fixed to the walls or ceilings in a secure manner. The type of support needed by the wires will depend upon the system of wiring. In order to fix the supports plugs or blocks of well-seasoned teak-wood are used Their size is 5 cm long and 2 5 cm square on the inner end and 2 cm square on the outer end, as shown in fig. 5.8. They are embedded into the wall, leaving a gap of 6.5 mm on the surface, which is later filled up with plaster or lime according to the nature of the wall surface.

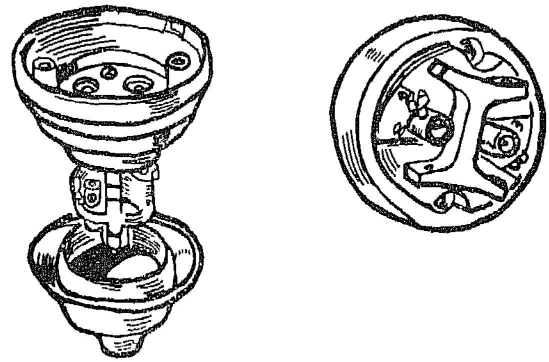


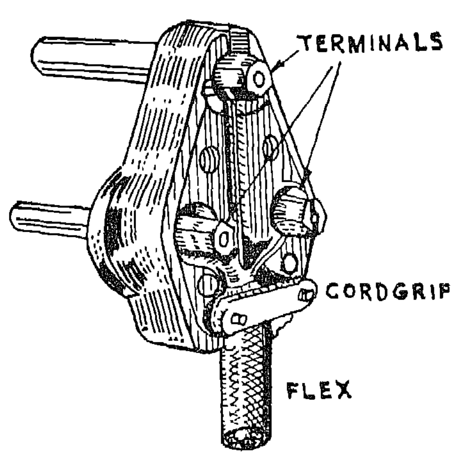
Fig. 5.9. Ceiling Rose

5-7. Fitting and Accessories

For 'points' on the ceiling, *ceiling roses*, as shown in Fig. 5 9, are used These, and similar attachments are used only up to a circuit voltage of 250 volts. Normally one flexible chord (flexible insulated wire) is attached to the two terminals of a ceiling rose. Incandescent lamps with a light-reflector may also be suspended from the same flexible chord. For lamps with heavy reflectors and shades, and for fans, firm support is provided separately from which they hang freely, and the flexible chord is used to connect the lamp or fan to the ceiling rose

A socket-outlet does not have any fuse terminal as an integral part of it; the fuse may be, if necessary, included in the plug. Every socket-outlet is controlled by a switch, which is located very near to it or combined with it The switch is needed only on the 'live' side of the line. Ordinary socket-outlets are fixed at a convenient place 23 cm above the floor level, and must be placed away from possible sources of mechanical injury. Power sockets and plugs, shown in Fig. 5.10, which are meant to give connection to devices drawing a current of 5 to 15 amps, are of three-terminal type, one for line (marked L), second for neutral (marked N) and the third for Earth (marked E). The two terminal sockets and plugs providing connection to L and N are of smaller diameter than the one marked for Earth connec-

tion For devices consuming currents less than 5 amps, such as lamps, only two socket-outlets and two pins will be provided, both pins being of the same diameter. The diameter of these pins or socket-outlets will be larger for larger currents When using the three-pin plugs, a third wire is necessary to connect the 'Earth' pin to the metallic body of the domestic appliances.



Every lighting fitting having lamps, fans and similar loads, is controlled by a switch and, where control at more than one point is necessary, by as many two-way and intermediate switches (to be described later) as there are control points.

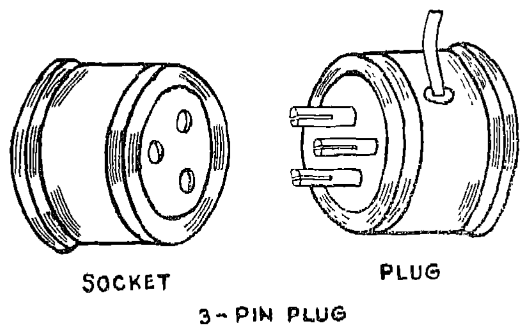


Fig. 5.10. Socket-outlet and Plug

There are many types of lamp-holders as shown in Fig 5.11. The lamp-holder has two terminals, connected to the ceiling rose, and holds the lamp so as to connect the terminals to the corresponding points of the lamp. An adapter is used sometimes to extend the point to some other location with the aid of a flexible chord.

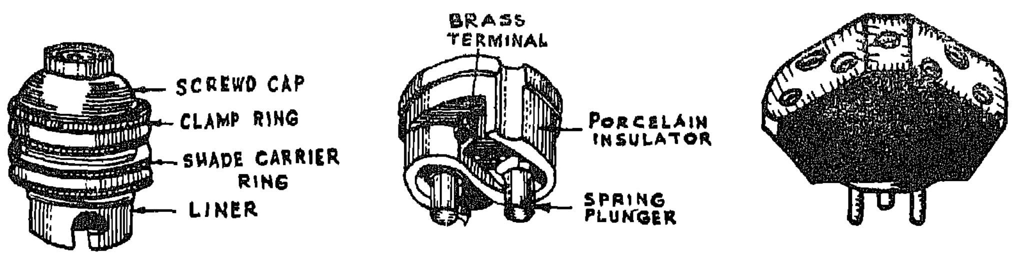


Fig. 5.11. Lamp-holder and Adapter

In all systems of wiring given below, except the conduit system, all ceiling roses, brackets, pendants (where lamp holders are attached) and such other accessories are mounted on teakwood blocks, which must have a minimum depth of 4 cm. Only wood screws made of brass are needed for attaching the fittings to the wood-blocks. Where teak or hardwood boards are used for mounting switches, regulators, etc., these boards are varnished well on all sides for better insulation.

5-8. Methods of Internal Wiring

There are various systems of wiring. The most suitable system should be chosen after a proper and complete study of the type of building or house, its environment, and the cost to be involved. The main systems of wiring are

1 the cleated wiring system;
2 the wood casing wiring system;
3 the tough rubber-sheathed (T R S.) and PVC-sheathed wiring systems,
4 the metal-sheathed wiring system; and
5 the conduit wiring system

5-9. Cleated Wiring System

This system is the cheapest of all, and mostly adopted for temporary installations, say, in a *pandal* raised to hold a religious ceremony or cultural show. This system should not be employed for wiring on damp walls or ceilings, as they damage the exposed insulation of the wires. In this system of wiring, the insulated wires are run through porcelain cleats, as shown in Fig. 5.12 The cleat is an insulated incombustible support (usually porcelain) normally used for insulated cables Usually, vulcanized rubber insulated cables are used. All cleats consist of two parts, a base piece and a cap Specially-patterned cleats are also available for corners and bends Cleats are fixed at distances not greater than 60 cm apart from one another and at regular intervals Where cleated wiring is laid along iron joist or over any other metal, the space between such metal and the cleats is filled with varnished wood fillet or clamp securely fixed to joist, so as to prevent the conductors from coming in contact with the metal along which they are passing. The cleats are attached to wooden plugs in the walls and ceilings of the temporary structure. For voltages up to 250 volts, the cleats should be of such dimensions that for branch loads, the distance between the centre lines of any two conductors is not less than 2 5 cm, and for sub-mains not less than 4 cm The size of the cleats varies according to the number of wires, 2-way cleats and 3-way cleats enabling 2 or 3-wire distribution. The grooves of porcelain cleats, for accommodating the wire, must not compress the insulation too much nor should they make the wire too loose Two wires should never under any circumstances be placed in one groove Where the cleated conductors cross one another, they are separated by an insulating bridging piece which will rigidly maintain a distance of at least 1.3 cm between the conductors.

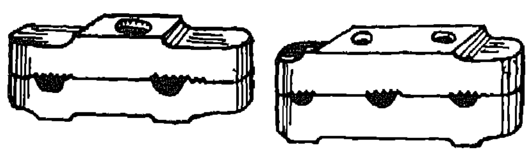


Fig. 5.12. Porcelain Cleat

5-10. Wood Casing Wiring System

In this system, insulated wires are placed in grooves made along a piece of seasoned teakwood, called wood casing, and another flat piece of wood, called capping, is placed over the casing, as shown in Fig. 5 13, and fixed together by means of screws This system is suitable for low voltage installations, such as house-wiring where vulcanized rubber

insulated or plastic insulated cables are used. The sizes of casing and capping for various sizes of 250-volts-grade insulated cables are given in the Indian Standard Codes of Practice No. 732—1963. Conductors of opposite polarity of different phases are never bunched in one grove in wood casing. All casings are fixed by means of suitable flat-headed wood-screws to wooden plugs set in walls at an interval not exceeding 60 cm.

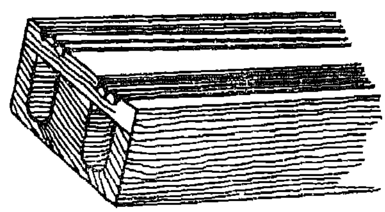


Fig. 5.13. Wood Casing and Capping

5-11 Tough Rubber-sheathed and PVC-sheathed Wiring Systems

Wiring with tough rubber-sheathed cables is suitable for low voltage installations, i e. for house-wiring and is not done in places exposed to sun and rain nor in damp places. Wiring with PVC-sheathed cables is suitable for medium *voltage installation* and may be installed directly under exposed conditions of sun and rain or damp places. This system is also suitable in places where acids and alkalies are likely to be present. (PVC is a chemical substance called polyvinyl chloride).

All sheathed cables on brick, stone or plaster walls and ceilings, steel joists, and any structural steel work are run on *wood battens* not less than 10 mm thick, and having a width sufficient enough to accommodate the cables. Fig. 5 14 shows the fittings of this wiring system. These battens are fixed on the walls and ceilings by screws to wooden plugs at an interval not exceeding 75 cm. *Link clips*, made of tinned brass, are used to secure the cables on the wooden batten The clips are so arranged that one single clip will not hold more than two twin-core TRS or PVC-sheathed cables sized up to 2 mm^2 Otherwise, a single clip can hold only a single twin-core cable. The clips are fixed on the wooden battens with the aid of brass pins or screws, and spaced at intervals of 10 cm for horizontal runs and 15 cm for vertical runs. The wiring, at any place, should never be so bent as to form a right angle, but should be rounded off at the corners to a radius which must not be less than six times the overall diameter of the cable It is usual to paint the TRS-wiring with one coat of oilless paint or distempter of suitable colour over a coat of oilless substance

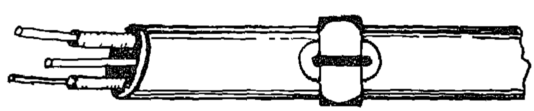


Fig. 5.14. TRS-wiring

5-12. Metal-sheathed Wiring System

This system of wiring has some similarity with the TRS system. The conductors of the cable are insulated with vulcanized rubber; some two or three insulated wires are covered with a sheathing of some metal, usually lead alloy. This system is suitable for low voltage installation, and is not used in situations

where acids and alkalies are likely to be present. This system may also be used in places exposed to sun and rain, provided all joints are kept carefully unexposed, it may be used in damp situations with proper precaution to prevent entry of moisture at the open-ends of the cable. Only tinned brass link clips are used They are so arranged that a single clip does not hold more than two twin-core cables, sized up to 2.00 mm², above which only one twin core cable is to be used. The clips are fixed on a varnished wooden batten with brass pins or screws, at an interval of 10 cm for horizontal runs and 15 cm for vertical runs Fig. 5.15 shows the arrangements for metal-sheathed wiring Joints are made by porcelain connectors in the joint-box The sheaths of the cables are *bonded* with the box, which means that sheaths will be in immediate contact with the metallic body of the joint box.

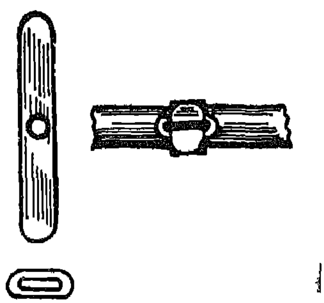


Fig. 5.15. Metal-sheathed Wiring

All lead sheathing and the exposed metal parts, joint-boxes, portable appliances and similar accessories are efficiently earthed, and made electrically continuous throughout by means of soldered joints or earth-continuity conductors The earthing is extended to all main switches, distribution boards, etc The electrical resistance of the metal sheathing, with the resistance of the earthing lead, measured from the connecting point with the earth electrode to any other point in the installation, should not exceed 1 ohm

5-13 Conduit Wiring System

In this system the insulated wires are run through steel conduits (or pipes) which are mostly enamelled or galvanized to give a smooth surface

Depending on their thickness and mechanical strength, steel conduits are divided into two categories—the *heavy gauge*, and the *light gauge* conduits The heavy gauge conduits may be of *solid drawn seamless type*, or of welded (with longitudinal seam) type This type offers very strong, water-tight wiring The light gauge conduits are made of thinner steel sheets with longitudinal seam, the ends on the seam being simply pressed This can be understood by looking at Fig. 5 16 which shows bot heavy gauge and light gauge conduits. A steel conduit, if less than 16 mm in diameter, cannot be used for wiring

Conduit pipes are jointed by means of *screwed couplers* and screwed accessories only. In long distance straight runs of the conduit, *inspection-type couplers* are provided at reasonable intervals. The conduit joints with couplers are shown in Fig 5 17 The threaded portion at the ends of the conduits in all cases is between 11 mm to 27 mm in length, so that the pipes can be accommodated fully into the threaded portion of couplers and accessories. Cut ends of the conduits are smoothened, because sharp edges may damage the insulation of the cables while they are being pulled through the pipes The maxi-

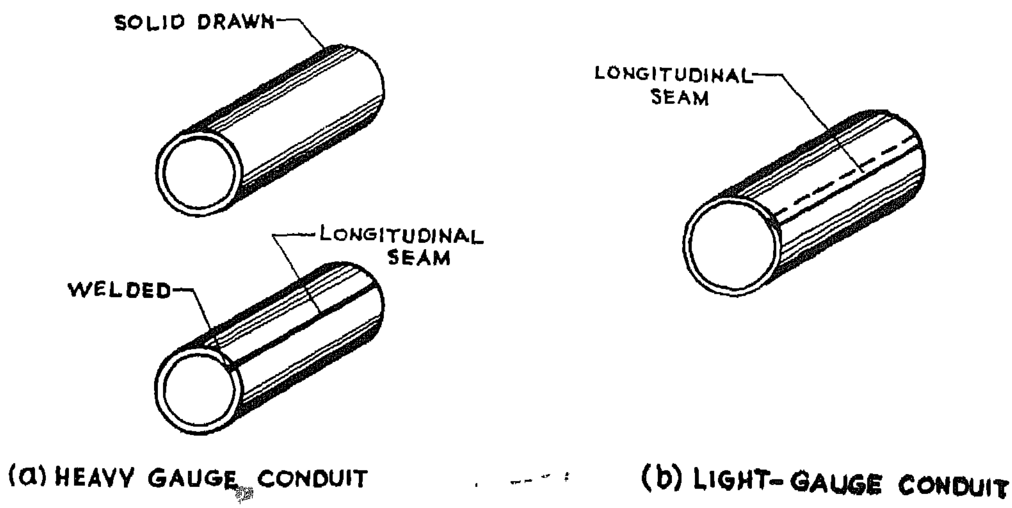


Fig. 5.16. Heavy-gauge and Light-gauge Conduits

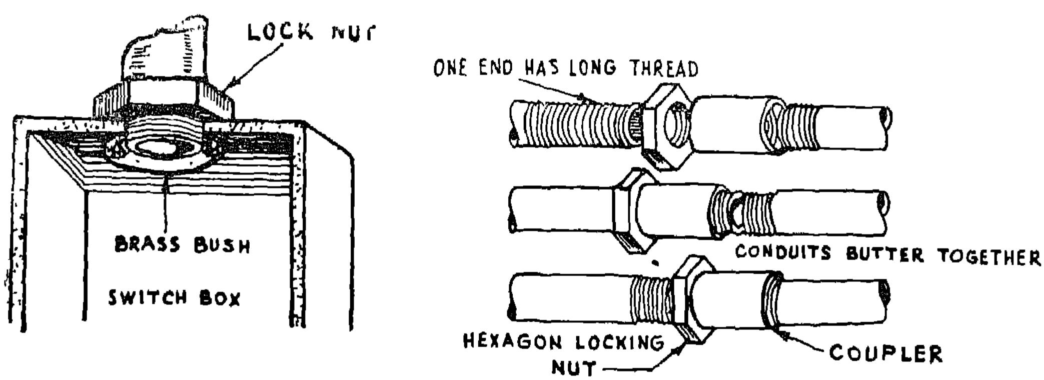


Fig. 5.17. Conduit Joints and Couplers

mum capacity of conduits for the drawing-in of 250-volts grade cables has been given in Table No 2 of the Indian Codes of Practice No IS· 732-1963

Conduit pipes are fixed by heavy-gauge saddles, screwed to suitable wooden plugs, as shown in Fig. 5.18, at an interval of not more than 1 m. But on either side of couplers or bends or similar fittings, saddles are fixed, at a distance of 30 cm from the centre of such fittings.

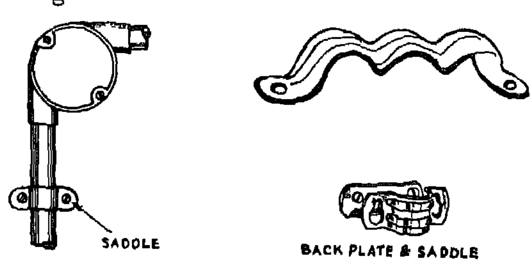


Fig. 5.18. Saddle and Fixing of the Conduits

All bends in the system including diversions are dealt with mostly by inserting suitable solid or inspection-type normal bends, elbows or similar fittings, by bending pipes or by fixing cast-iron inspection boxes. The radius of bends must always be greater than 7.5 cm. Fig 5.19 shows the conduit fitting with bends and elbows.

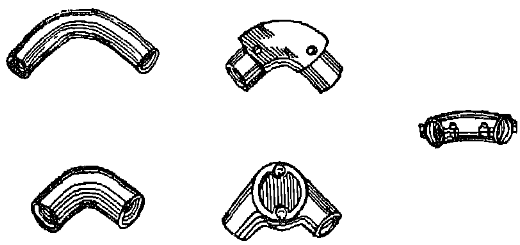


Fig. 5.19. Conduit Bends and Elbows

All outlets for fittings, switches, etc are in the form of boxes of suitable metal, usually cast iron. These boxes may be of surface-mounting type or flush-mounting type. The former will project out of the plane of the wall or ceiling, while the latter will get *flushed* or end at the plane.

All conductors used in the conduit wiring system are preferably stranded. In A.C. no single-core cable of nominal cross-sectional area greater than 130 mm² can be enclosed singly in a conduit. This is because of the possible heating of the conduit due to the eddy-currents induced in it by the A C.

The conduits of all sections are completed before the drawing-in of the wires. After erection, the entire conduit system is tested for mechanical and electrical continuity throughout. It is permanently connected to earth at a suitable position. Neither gas nor water-pipes are used as earthing electrode.

In the recessed or concealed conduit wiring system, the conduit is placed in the chase in the wall A chase is a system of grooves cut in the wall to accommodate the conduits. For buildings under construction, chases are provided in the walls and ceilings at the time of construction, and are neatly filled up after erection of conduit and brought in to exact line with the surface of the wall. The conduits are fixed in the chase by means of staples or saddles, one being spaced 60 cm apart from another. Fixing of standard bends, elbows, etc, are avoided, and the conduit itself is bent to the required degree. The radius of bend is such as to facilitate drawing of the wires. Suitable inspection-boxes are provided and mounted flush with the wall with an eye to periodical inspection and removal of wires, if necessary. Suitable ventilating holes are provided in the inspection-box covers. All outlets may be either of the flush-mounting or surface-mounting type.

5-14. Earthing

All non-current-carrying metal parts of electrical installations are to be earthed properly for the safety of life and property. All metal conduits, cable sheaths, all metallic bodies housing the switches and the distribution fuse-boards, lamp fittings and other exposed metal parts are bonded together and connected by means of two separate and distinct conductors to an efficient earth electrode. Earthing is never done through any structural metal-work of the house containing the installation.

5-15. General Rules Applying to all Systems of Earthing

The *main earthing conductor* runs from the 'earth' connection at the main

switch board to an earthing electrode to which it is connected The *sub-main earthing conductor* is run from the main switch board and any other point of the *Circuit earthing conductor* is run from the exposed metal of any equipment and is connected to any point on the main or sub-main earthing conductor The electrical resistance of metallic enclosures of cables and conductors measured between earth connection at the main switch board and any other point of the metallic body of the installation should be low, not in any case exceeding 2 ohms. This is necessary to permit the passage of sufficient short-circuit current to operate the fuse or other protectitve devices

Every earthing conductor is made of high conductivity copper and should be either of stranded, flat strips, circular rod or the rectangular bar type. Galvanized solid iron, steel wire or rod may also be used, provided conductivity is not less than that of the copper earthing conductor The cross-sectional area of the copper-earthing conductor should not be smaller than half that of the largest current-carrying conductor, subject to an upper limit of 65 mm^2.

Earth electrodes may be of three types: *Driven electrodes, Strip electrodes,* and *Plate electrodes.*

Driven electrodes or Pipe electrodes are made of metal rod or pipe having a clean surface not covered by paint, enamel or any other poorly conducting material. Rod electrodes of steel or iron should be at least 16 mm in diameter Rods of non-ferrous metals should be not less than 12.5 mm in diameter. Pipe electrodes have a minimum internal diameter of 38 mm, and if made of steel or iron the outer surface will be galvanized They are driven to a depth of 1.25 m in normal soil, and 2.5 m in rocky soil

Strip electrodes consist of copper strip not smaller than 25 x 1.60 mm in cross-section or bare copper conductor not smaller than 7/0.75 mm (3.0 mm^2). The length of buried conductor should be sufficient to give the required earth resistance. The strips are buried in a trench, at least 0.5 m deep, with electrodes as widely distributed as possible

Plate electrodes should be not less than 60 cm x 60 cm x 6 30 mm for galvanized iron or steel plates, and 60 cm x 60 cm x 3 15 mm for non-ferrous metal. They are buried into a depth of not less than 1.5 m

The earth-resistance of the driven or buried electrode should not exceed a value.

$$\frac{0.5 \times \text{voltage to earth}}{2.5 \times \text{current rating of largest fuse}} \text{ ohms.}$$

5-16. Insulation Resistance of Installations

For the safe operation of the distribution system, the insulation resistance between any live conductor and earth should be very high to prevent leakage. The insulation resistance is measured by applying a D.C. voltage between earth and the whole system of conductor or any section of it, with all fuses in place and all switches closed, and all lamps in position or both poles of the point otherwise electrically connected. The D.C. voltage applied should be at least twice the working voltage, but not exceed 500 volts in medium voltage circuits. Under this condition, the insulation resistance measured must not be

less than

$$\frac{50}{\text{number of points in the circuit}} \text{ megohm}$$

(10^6 ohms)

5-17. Conventional Symbols for Electrical Installations

The various parts of electrical installations are represented in the electrical wiring-diagrams by corresponding symbols. These symbols are given in Appendix B of the Indian Standards Codes of Practice Book No IS 732—1963, page 51.

5-18. Controlling a Lamp by Two-way and Intermediate Switches

When a lamp is controlled by one switch, it makes contact in the 'on' position and breaks it in the 'off' position This means that the switch makes connection in one way only; hence such switches are called single-way or one-way switches.

When it becomes necessary to control a lamp from two places, as for staircase lighting, another type of switch, called a 2-way switch, is used. A 2-way switch makes connections in both ways on two contacts A and B, as shown in Fig. 5.20. When the first switch is on A, the second switch must be operated to make contact at A, and when second switch is on B, the first switch must be on B, to switch the light on. If the circuit is observed carefully, one can easily understand that the light can be put 'on' or 'off' from each of the two positions shown in the figure.

When it becomes necessary to control a lamp from 3-points, two 2-way switches and one *intermediate-switch* are used, as shown in Fig 5.21 An intermediate switch has four terminals and two contact bridges called *dolly* In one position the connectitons are made (as shown) by the two full lines, and in the other position, by the two dotted lines By following the diagram, one can understand that if the light is 'off' in a particular position of the intermediate switch, it can be changed to 'on' by shifting the switch to the other position

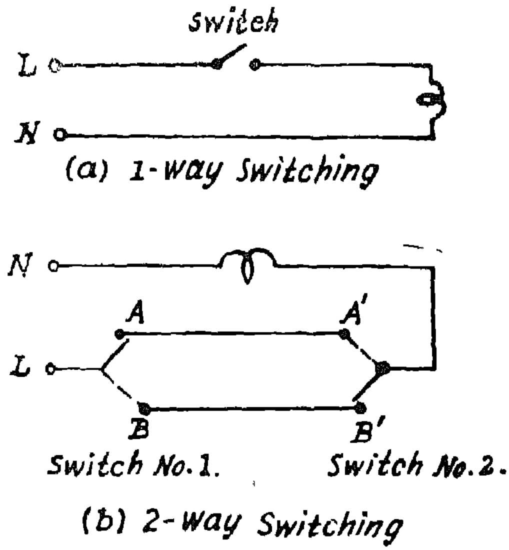


Fig. 5.20. Two-way Switching

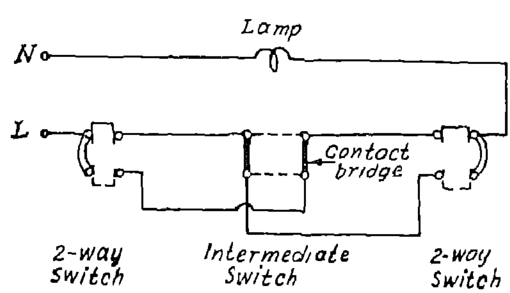


Fig. 5.21. Connections of Two-way and Intermediate Switches

5-19. Switchgear and Relays

A switchgear consists of switches and other accessories required to control a circuit. An ordinary switch, controlling a light, fan or similar small loads, is operated by hand for both connecting or disconnecting the device. There is no automatic circuit-interruption device between such a switch and the lamp. But for the main switch, although the circuit can be connected or disconnected at will by operating the switch, there exists an automatic device which can disconnect the circuit automatically when the circuit carries any dangerous current. This device is the fuse, as has been shown earlier. The time required by the fuse to blow or disconnect a circuit depends upon the *excess current.* For currents up to 100 amps, fuses are usually the only protective devices in the domestic installations. For industrial installations of larger current carrying capacity, fuses for currents up to 600 amps are available.

The common type of fuse-unit consists of a porcelain base with two fixed contacts, and a fuse-carrier with two corresponding contact-blades. The fuse-wire is connected between two terminals on the two blades, and the carrier is placed on the base which secures the fuse completely covered. Another pattern of fuse is known as a 'cartridge' fuse where the fuse-wire is a silver wire surrounded with fine powder in a cardboard or glass cartridge. Details of this are shown in fig. 5.22. This type of fuse is said to have a 'high rupturing capacity' (HRC) and is suitable for higher currents. In high and extra-high voltage circuits the current flowing due to accidental short-circuits may be a few thousand ampere current. HRC fuses can interrupt such currents, and disconnect the faulty circuit in about 0.2 to 0.5 second. For many extra-high voltage circuits, the resulting arc after the fuse has melted or blown may not be extinguished quickly enough, and the high short-circuit current may cause extensive damage to the equipment through which it flows. In such cases fuses are not considered advisable.

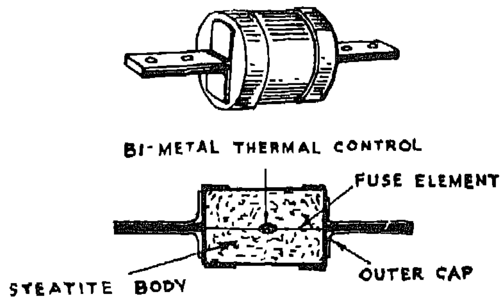
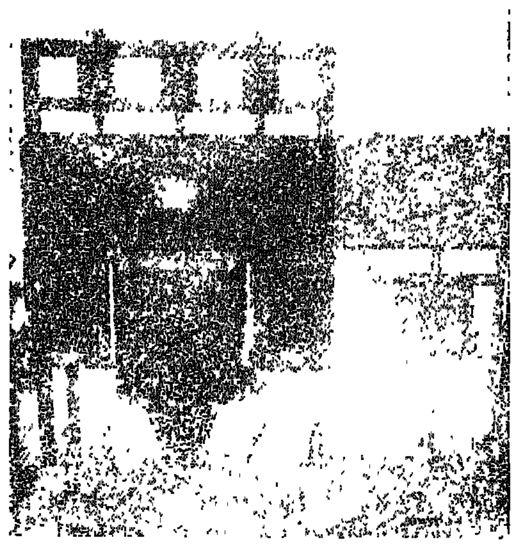


Fig. 5.22. A Cartridge Fuse



A Low-voltage Switch-gear

In most high and extra-high voltage installations, protection by fuse alone has been found to be unreliable Hence, automatic protection in such cases consists of a fault-detecting device and a circuit-interrupting device. The basic principle is that when a short-circuit occurs involving two or more conductors normally with a potential difference between them, an abnormal current flows which actuates a *relay*. This relay causes one or more *circuit breakers* to break the circuit.

A circuit-breaker is essentially an arc-extinguishing device. When one tries to separate two contact members of a current-carrying contact, an arc is initiated between the contact members. In circuit breakers, this arc is extinguished with the help of highly insulating oils or high velocity air moving across the arc between the contact members, and so the breakers are called 'oil circuit breakers' (OCB) or 'air circuit breakers' (ACB) respectively.

A relay is an electromagnetic device. It consists of one or more coils through which a short-circuit current or a part of it flows When this current is of an abnormal value it is sufficiently magnetized to attract some iron piece. This will cause the tripping device of the circuit breaker to act and break the circuit. In many other schemes, the abnormal currents and voltages in the relay windings may cause a disc of the relay to close one or more contacts. The closing of these contacts results in the flow of currents in some solenoids attached to the circuit breakers The plunger of the solenoids then gets attracted and causes the circuit breaker to disconnect the circuit

QUESTIONS AND EXERCISES

1 Name the electrical appliances that get connected to (i) Power and Heating sub-circuit, and (ii) Lighting and Fan sub-circuit. What is the difference between the two sub-circuits?

2. What is the purpose of having "main" and "branch" distribution boards?

3 What is the minimum cross-section of wire that can be used in the sub-circuit wiring?

4. How are junctions made for branching out circuits?

5 How are switches and switch boards mounted? How would you make a switch-board?

6 How are the loads distributed from the distribution boards? What is the maximum load that can be put on a circuit outlet?

7 How are the various sub-circuits of an indoor wiring system protected against short-circuits? Describe the protective device employed.

8 What are the general rules for the wiring passing through the walls and under the floors? How are the various fittings fixed to the walls and ceilings?

9 State the rules regarding the fittings of socket-outlets and plugs

10. What are the various types of lamp-holders?

11 Give the various systems of indoor wiring and indicate their possible applications.

12 What are the general rules to be followed for the following systems of wiring?
(i) Cleat wiring, (ii) Wood-casing wiring, (iii) TRS or PVC-wiring, (iv) Metal-sheathed wiring, (v) Conduit wiring

13. What is the difference between light-gauge and heavy-gauge conduits?

14 Write short notes on the following
(i) Couplers, (ii) Capacity of the conduit; (iii) Saddles; (iv) Tees and Elbows; (v) Chase.

15 Why is earthing necessary in the indoor wiring systems? State the general rules applying to all systems of earthing.

16 What is the difference between a "main earthing conductor" and a "circuit earthing conductor"?

17 What are the various types of earthing electrodes?

18 What should be the maximum value of earthing resistance?

19 How is the insulation resistance of an installation determined? What should be the minimum value?

20 Show, by a diagram, how you will control single lamp from two different places

21 What arrangement will you make to control a lamp from more than two places?

22. What is meant by "HRC-fuses"? How are these made and where are they used?

23 What is a "circuit-breaker" and what is its purpose?

CHAPTER 6

Generation, Transmission, Distribution and Utilization of Electrical Energy

The primary source of energy in the earth is the Sun. The direct solar energy which is radiated from the sun in the form of heat cannot be utilized very conveniently, although attempts are being made to harness it.

The energy in the wind, derived from the sun through its unequal heating of the various parts of the earth, has been utilized for many years in windmills for crushing wheat. Windmills can also drive small generators of electricity, which can, in turn, charge storage batteries for constant use.

6-1. Sources of Energy

The main sources of energy for generating electrical power are fuels like coal and oil, and water-power Heat energy, released by burning the fuels, can be utilized by steam-turbines and engines to drive generators of electricity Water-power is available from rivers and water-storage reservoirs When water flows from a higher to a lower level, the kinetic energy of the flowing water is utilized in water or hydraulic turbines for driving electrical generators

Internal combustion engines using petrol are suitable for generating comparatively small power in mobile units, such as road traffic vehicles and small crafts in rivers. Diesel engines using diesel oil are suitable for generating electrical power in power stations of small capacities In larger power stations, heat is released in the *boilers* by burning coal or oil, and is used to produce steam from water at a high temperature and pressure. The steam is used by the steam-engines and steam-turbines to drive generators of electricity

The heat-energy contained in fuels is expressed in Kilocalories (K cal). One K.cal of heat represents the amount of heat necessary to raise the temperature of 1 Kg. of water by 1 degree centigrade The electrical energy is expressed in kilowatt-hours (Kwh). The units of heat and electrical energy are related to each other by

$$1 \text{ Kwh} = 860 \text{ K. cal.}$$

The *heat-values* of fuels are usually given as so many K.cal per Kg, and is also known as the *calorific value* of the fuel The heat-value of coal varies considerably depending on the grade of coal.

Good grades of coal have an average heat-value of 6700 K cal per Kg If all the heat-energy in a fuel could be converted into electrical energy, 1 Kg of fuel could give out 7 8 Kwh But usually, the efficiency (which is the ratio of output to input) of the power plant comprising the boiler, turbine and generator is about 25%. Hence the energy converted by 1 Kg. of fuel will be about 7.8 x 0 25 or 1 9 Kwh, or, in other words, to generate 1 Kwh of electrical energy about 0.5 Kg. of coal is necessary

The lower grades of coal have less heat values. *Lignite* or *brown-coal* and *peat* are of this category, and may have a calorific value of the order of 3500 K cal per Kg Heavy oils have higher calorific values of the order of 11500 K.cal per Kg

6-2. Steam Power Stations

In steam power stations, the fuel used is coal, lignite or peat. The heat-energy stored in the fuel is converted into mechanical energy by running the turbines with steam from the boilers The turbines act as prime movers to drive the generators of electricity and convert the mechanical energy into the electrical energy

The energy-exchanges in a steam power station take place through the following circuits, as shown in Fig 6 1, where the width of each circuit represents relative amounts of energy. Fuel is fed into the boiler with air, the oxygen of which is necessary for the complete combustion of the fuel. In the boiler the fuel gives up most of its energy to the water and steam, and a much smaller part of its energy escapes into the outer atmosphere in the form of heated gas, called "flue-gas" The steam with its heat energy is forced from the boiler into the turbine, where a major part of its energy is converted into mechanical form, and is transmitted to the generator through the coupling shaft. The steam with its remaining energy leaves the turbine as *exhaust steam* and enters the condenser. In the condenser, the exhaust-steam is almost completely

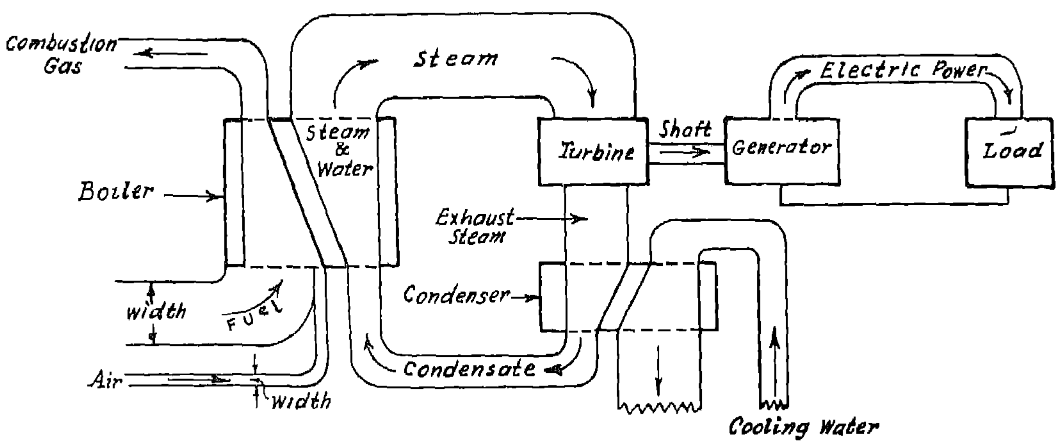


Fig. 6.1. **Energy Transformation in a Steam Power Plant**

condensed when cooled with the help of water. The condensed steam, called the condensate or boiler feed-water, is fed back into the boiler. This completes the *steam-circuit* The cooling water, which absorbs some heat from the steam during the process of condensation, may be supplied from the up-stream-side of a river and discharged to the down-stream-side. Where adequate cooling water is not available from a river, the same water is circulated over and over again through the *cooling towers*, or spray-ponds, in which the heated water from the outlet of the condenser is cooled and fed back to the inlet of the condenser The greater part of the mechanical energy supplied to the generator is converted into electrical form and is consumed by the electrical loads. A very small part of the mechanical energy input is wasted as losses in the generator and the electrical transmission circuit stretching from the generator to the load. From the description given above it is now evident that there are four circuits in a steam power station, namely,

(i) air and gas circuit,
(ii) steam circuit,
(iii) cooling water circuit and
(iv) electrical circuit

Other important parts of the steam power plant are: economiser, superheater, air preheater and feed water heater.

The *economiser* is placed in the flue-gas circuit, where a portion of the heat of the fuel-gas is utilized in heating the boiler feed-water.

The *superheater* heats the steam further inside the boiler to give more energy per unit volume of the steam

The *air preheater* is also placed in the path of the flue-gas to extract the remaining heat further for heating the air going into the boiler

The *feed water heaters* utilize the heat of the *bleed-steam*, which is a portion of the steam taken out of the turbine before the final exhaust

In addition to these parts, there are some very important fans and pumps, usually driven by electric motors of large capacities.

The *forced draftfan* is an *air-pump* which forces air into the boiler for supporting the combustion of the fuel

The *induced draftfan* is another air-pump which draws the hot volatile gases out of the boiler to be rejected into the atmosphere through the *chimney*.

The *boiler feed-pump* forces the condensate and feed water into the boiler against the high pressure existing inside the *boiler drum*

The *condensate-pump* helps to draw the condensate out of the condenser and circulate through the feed heaters

The steam power stations are located at a site, preferably near the premises of a large number of electricity consumers. At the same time, adequate cooling water must be available at the site, and also the transport cost of the fuel should be the minimum possible. There must also be an efficient and cheap arrangement for disposing of the ash which remains after the combustion of the fuel

Fig. 6 2 shows a thermal power station with its various parts

6-3. Hydro-electric Power Stations

Since the source of power in a hydro-electric station is the kinetic energy of the flowing water, it is obvious that the conditions at the station should be such as to obtain the maximum possible flow of water Water maintains a natural flow when there is a difference of level between the upstream and the down-stream sides In some cases, this difference of level exists naturally, as in the water-falls of large rivers. But in most cases the difference in level is created artificially by impounding water by constructing *dams* across the rivers, so that the water level on the up-stream-side goes on rising as more and more water is accumulated. The actual difference in the level of water depends on the rate of *inflow* and *outflow* of water The dam provides not only the difference in level but also facilitates and ensures storage of water, which may be utilized when the consumer's demand reaches the peak The water from the

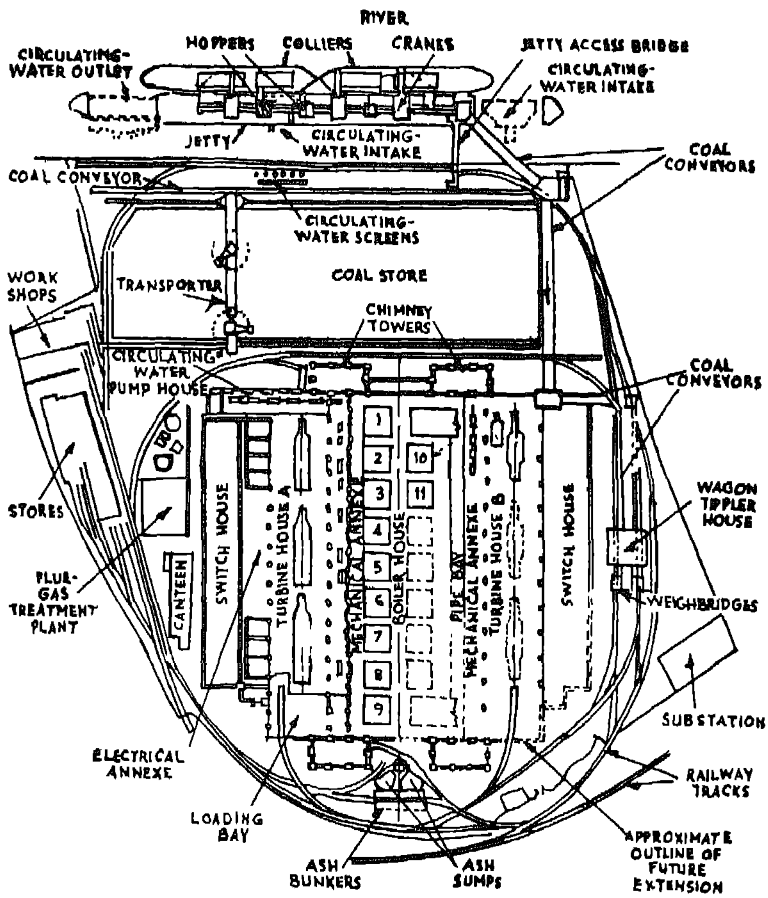


Fig. 6.2. The Lay-out of a Steam Power Station

Machine Room of the New Cossipore Power Station, Calcutta.

up-stream-side is guided to the power house through the penstocks, which discharge the water to the inlet of the hydraulic turbines. The turbines convert most of the kinetic energy of the flowing water into mechanical energy. The remaining part is treated as loss in the turbine and pipes The mechanical energy of the turbine is transmitted through a coupling shaft to the electrical generator A very small part of the total kinetic energy of the water is carried away with itself as it is discharged by the turbine to the outside atmosphere through the tail-race. Fig. 6.3 shows, in outlines, the arrangements of utilization of water power.

The types of prime movers or turbines used for driving hydro-electric generators depend on the difference of level of water, known as hydraulic head. For low heads up to 50 m vertical shaft *Francis turbine* is used. Some modified forms of Francis turbines can be used

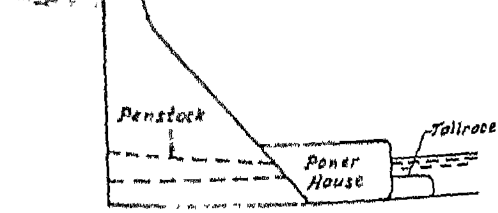


Fig. 6.3. Energy Transformation in a Hydro-electric Power Plant

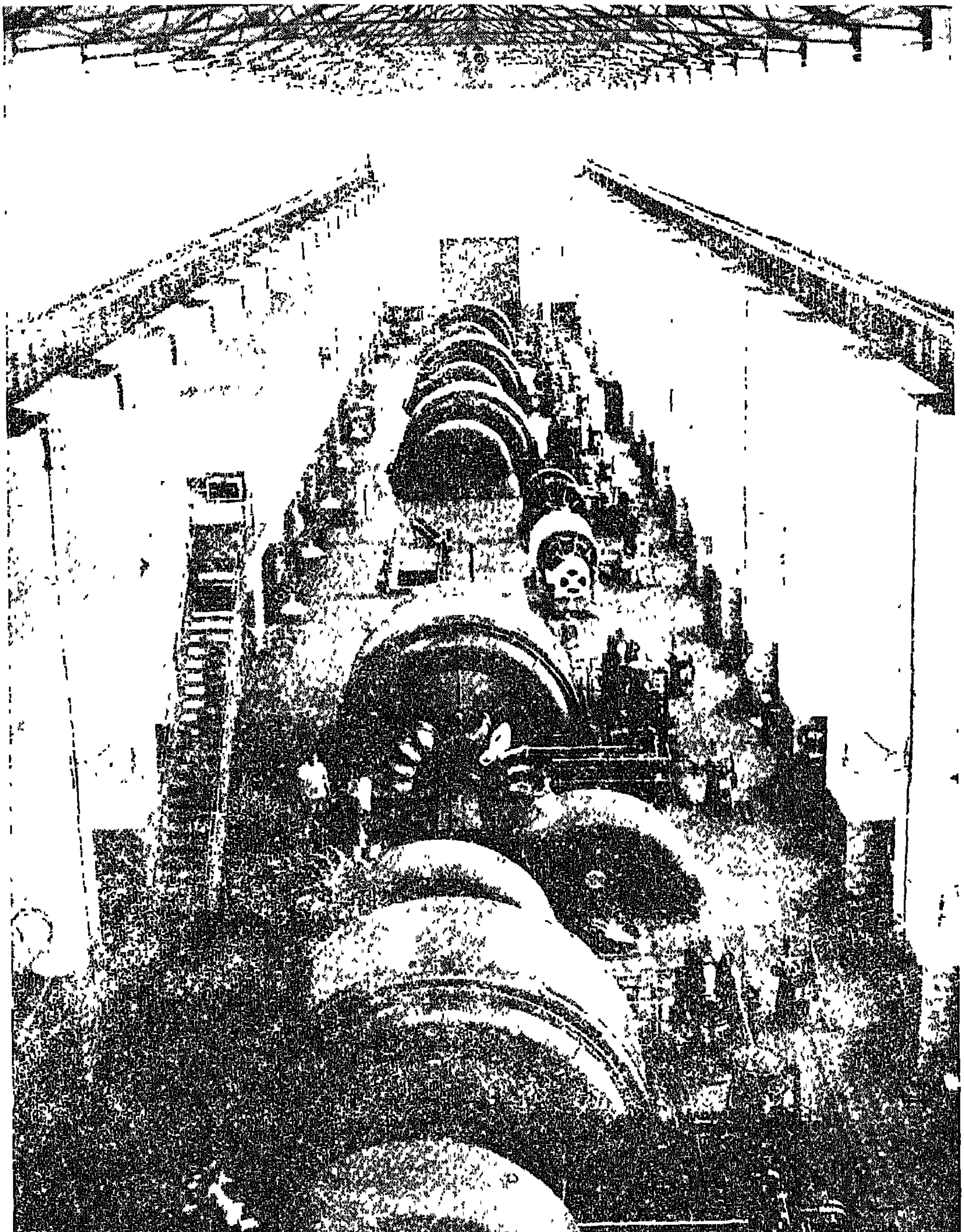


Fig. 6.4(a)

Water-wheel Generators in a Hydro-electric Power Station.
Courtesy of the Tata Hydro-Electric Power Supply Co. Ltd.

for heads up to 200 m, and the shafts may be horizontal For heads above 175 m usually another prime mover called the *Pelton wheel* is used. *Kaplan* and *Propeller* turbines are also used for low heads.

Most hydro-electric power stations are located at sites which are usually quite distant from places where electricity is consumed This is because im-

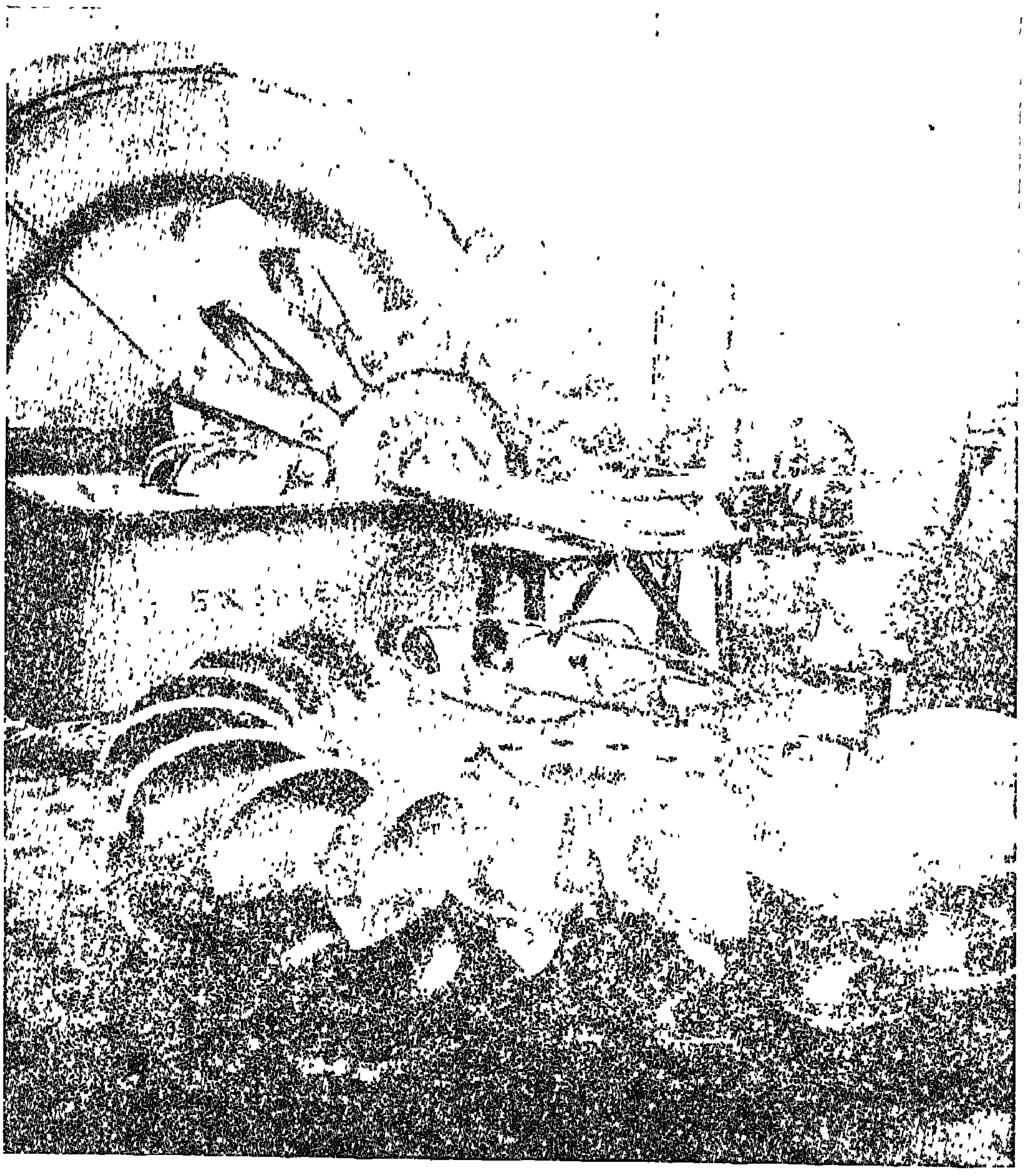


Fig. 6.4 (b)
An opened-out Hydraulic Turbine.
Courtesy of the Tata Hydro-Electric Power Supply Co. Ltd.

pounding of water in vast quantities by dams is not possible in thickly populated and industrial areas Fig 6.4 (a and b) gives a view of the various parts of a hydro-electric power station.

6-4. Transmission of Electrical Energy

It has been seen that because of the usually remote location of the hydro-electric power stations, electrical energy has to be *transmitted* from power stations to the centres of consumption Also, in some cases, steam stations are located at remote places because of the easy availability of cheap fuel and adequate cooling water at the site

The most common method of transmission of electric power (which is the rate of flow of energy per second) is by means of overhead conductors or lines, mounted on poles. The other method is the use of underground cables The first method is much cheaper than the second The second method is used when the power is to be transmitted through fairly densely populated areas

As mentioned earlier, electrical power is generated in the form of A C., and by a 3-phase system. It is economical to transmit power by High voltage A C, because for a given transmitted power the current decreases as the voltage is increased (since power $P = V \times I$), and the reduced current in the transmission lines will reduce the power loss in them (since power loss $= I^2 \times R$). The high voltage for transmission is obtained by stepping up the generated voltage through the use of transformers The voltage of transmission increases with the increase of both transmitted power and the distance over which it has to be transmitted The transmission voltages commonly adopted in India are 33, 66, 132 and 220 KV In many advanced countries this voltage is raised as high as 400 KV

Conductors for overhead lines are usually *stranded*. If a solid conductor is used, it will break at the point of support, due to continuous vibration by the wind and fatigue caused by the tension of the hung conductor Stranded conductors usually have a central wire around which are wrapped successive layers of wires, the number of wire in each layer rising over its preceding layer by sixes (6, 12, 18 and so on). If there are n layers, the number of strands will be $3n(n+1)+1$ If the diameter of each strand is d, the diameter of the cable or stranded conductor is $(2n+1)d$. The adjacent layers are spiralled in opposite directions to ensure compactness of the whole strand. Fig 6 5 shows the cross-section of a stranded conductor The most important material for overhead conductors is hard-drawn copper,

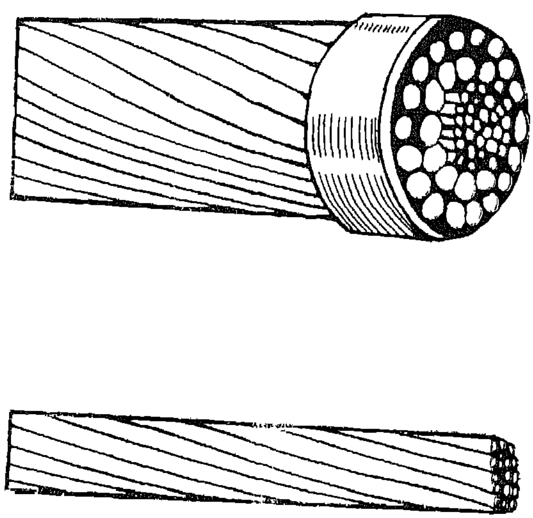


Fig. 6.5. Stranded Conductors

because of its high mechanical strength and high conductivity Stranded aluminium conductors with a certain number of steel strands at the centre are used extensively now-a-days for the extra-high voltage transmission lines. They are known as ACSR (Aluminium Conductors Steel Reinforced) conductors. Other materials used are cadmium copper, phosphor bronze, and galvanized steel The choice of materials is governed by considerations of cost, required electrical and mechanical properties, and local atmospheric conditions.

The line conductors are supported by structures called *poles or towers* Cross-*arms* which support the insulators are fitted on the poles, as shown in Fig 6 6.

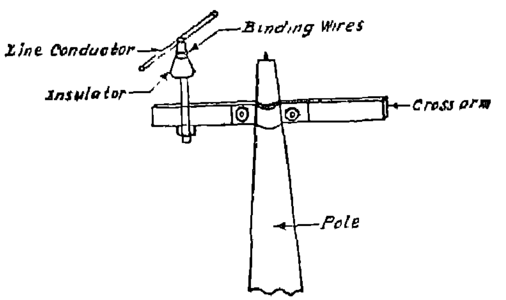


Fig. 6.6. An Overhead Line Pole

The line conductor is fastened to the insulator by *binding* wires. The width of the cross-arm depends upon the *spacing* or the distance by which the line conductors are separated from one another The spacing is determined by the voltage of the line. If the conductors are too close, short-circuits may take place between conductors or between a conductor and the pole-body on account of the high voltage existing across them. Sometimes swinging of conductors, due to stormy winds, may be noticed and that may result in short-circuits or arcing. The higher the voltage, the greater is the spacing required, and the greater will be the length of the cross-arm Also, the higher the voltage, the larger will be the size and weight of the insulators, which will again need stronger cross-arms of larger weight. Hence the poles, too, or the support needed will have to be more robust In actual practice, when the voltage of transmission exceeds 33 KV, the poles are no longer able to support the required load and, hence, a more robust structure, called the *tower*, is used A tower is made of galvanized iron pieces of angular cross-section and looks like a latticed structure. Fig 6.7 shows a steel-tower The tubular poles commonly used may be of wood or steel *Rail-poles* are also used for voltages up to 11 KV. The cross-arms are made of galvanized steel of channel cross-section The cross-arms of the tower are made with galvanized angle-iron pieces, latticed in form. All the joints are rivetted.

Porcelain and glass insulators are used to insulate the transmission line

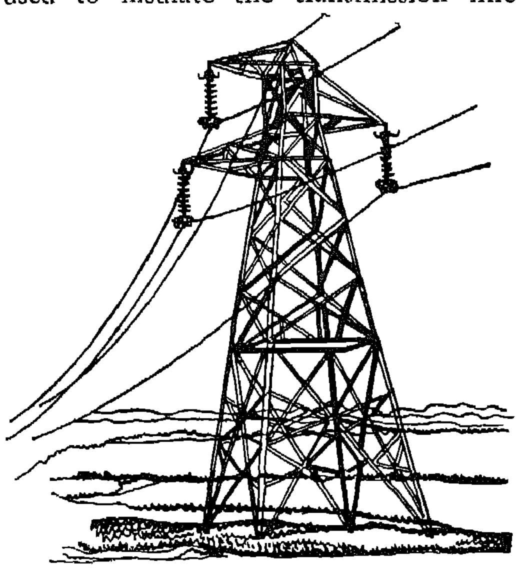


Fig. 6.7. A Transmission Line Tower

conductors from the metallic supports. The type of the insulator depends mainly upon the voltage and to some extent on its mechanical strength. For voltages up to 33 KV *pin- and shackle-type* insulators are used. For higher voltages, *suspension-* or *disc-type* insulators are used. As the voltage increases the number of discs in a *string of insulators* is also increased to raise the level of insulation. Fig 6.8 shows some common types of transmission line insulators

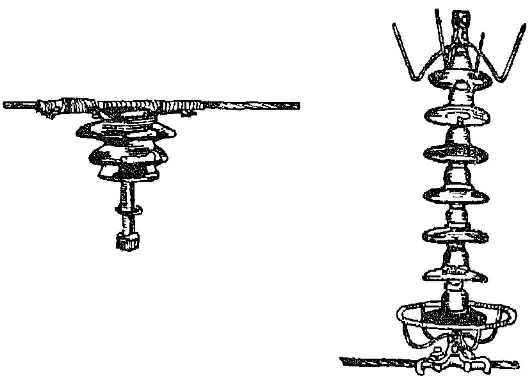


Fig. 6.8. Transmission Line Insulators

All metallic parts of the transmission line, which do not have any voltage with respect to earth, must be connected with earth, so that they are at the same potential as earth. This is necessary for the safety of any person or object that may come into contact with those parts, if they become *alive* by chance, owing to the failure of the insulator. This fact can be easily understood by referring to Fig 6.9. The *neutral* of the source of the voltage, which may be a generator or a transformer, is connected to earth, and the phases A, B and C are connected to the three-phase conductors of the transmission line. Now, if an object on earth is accidentally connected with a phase conductor, which has a voltage with respect to earth, it will get charged, and if the object is a human being, he will get a shock and may die. But if the object mentioned above touches another earthed object, it will not get charged, because both are at the same potential.

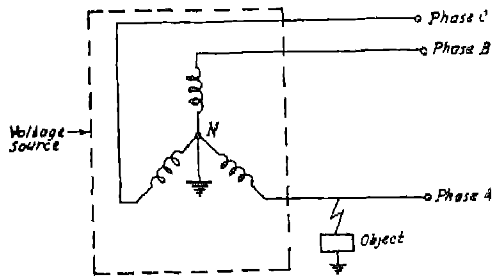


Fig. 6.9. A Three-phase System

This can also be achieved by running a continuous earth-wire from tower to tower, with the earth-wire connected to ground, say, at two points in each kilometre. Methods of earthing are expalined in detail in chapter 5.

6-5. Distribution of Electrical Energy

The electrical power, whether generated in a local power station or received from a remote station over the transmission lines, must be *distributed* efficiently and economically to all the consumers of electricity.

Small towns with low-capacity stations may have a generation voltage equal to the voltage of distribution. In such cases, the A.C. distribution usually consists of a three-phase four-wire system, as shown in Fig. 6.10. Two voltages VL and

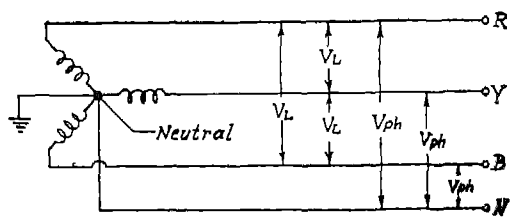


Fig. 6.10. A Three-phase Four-wire System

V_{ph} are obtainable simultaneously in this system, with $V_L = \sqrt{3}\, V_{ph}$. The magnitude of the voltages (between phase conductors R, Y and B, given by V_{RY} V_{yb} and V_{BR} are each equal to V_L (called usually the line voltage), and voltages V_{rn}, V_{yn} and V_{bn} are each equal to V_{ph} (called the phase-voltage) The higher voltage V_L is generally meant for consumers who have fairly large motor-loads, each exceeding about 3 Kw These loads are *three-phase loads*, which means that they represent equal impedances of identical power factor in all the three phases, and are connected to R, Y and B terminals either in star or in delta fashion. The lower voltage V_{ph} is usually used by domestic consumers with lights, fans, radios and other household appliances These are called *single-phase loads*, and are connected between any one of the three lines R, Y and B and the neutral point N which is at earth potential. It is necessary to connect three equal impedances of identical power factor from the R, Y and B lines for maintaining equal voltages across each one of the lines and neutral N. Under this condition the load connected to the three-phase supply is said to be *balanced* The three-phase power-loads are inherently balanced Hence, while distributing the various single-phase loads, care has to be taken to distribute them more or less equally from the three-phase conductors. The nominal value of the standard line voltage V_L = 400 volts, and of the phase-voltage,

$$V_{ph} = \frac{400}{\sqrt{3}} = 230 \text{ volts at a fre-}$$

quency of 50 cycles per second (c/s).

Fig. 6 11 shows two balanced loads across a three-phase four-wire source of voltage The first load consists of three equal resistances R (representing domestic type loads) connected to the three-phase conductors and the neutral The second load consists of three equal impedances Z (which may represent a motor load), connected in delta fashion, to the phase conductors, or lines, as it is called. If the three branches of a star-connected load do not have equal impedances, the currents in the three phases of this load will be unequal and will not be able to balance one another. If the load-neutral is connected to the supply-neutral under this condition, a resultant current will flow through the neutral conductor from the load-neutral to the supply-neutral The magnitude

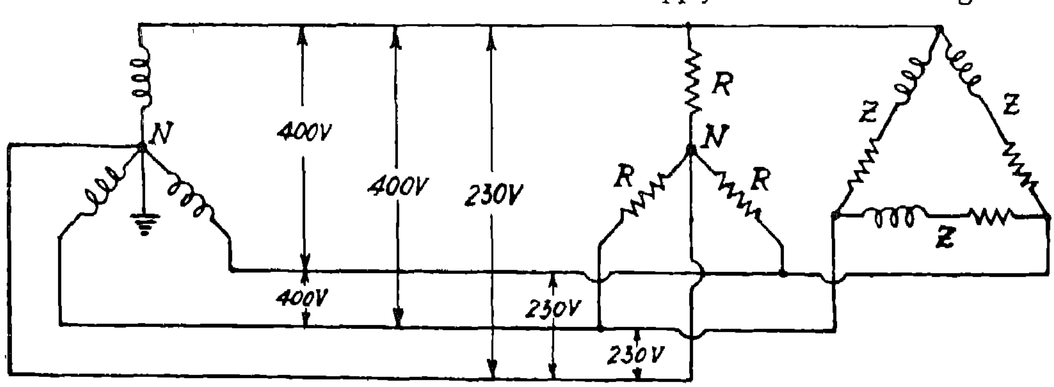


Fig. 6.11. Star and Delta Connected Load

of this current depends on the degree of unbalance. For balanced load, no current flows through the neutral wire even if the two neutrals are joined.

Some small towns still retain the old D C power generation and distribution system. In this case, a main D C generator G generates electrical power at the nominal voltage of 440 volts. Two identical D.C machines, comprising the *balancer-set*, as it is called, are connected in series across the positive and negative terminals of the generator The intermediate junction of the two machines is connected to earth, and a neutral line N runs from this terminal. The other two lines are called the *positive-outer* and the *negative-outer lines*. The arrangement is shown in Fig 6.12 The balancer-set maintains equal voltages between the positive-outer and N and negative-outer and N whenever there is an unbalanced load. Large motor-loads may be connected directly between the two outer lines

When the electrical power is not generated locally, but received from another station over a transmission line at a higher voltage, step-down transformers are used at the receiving station to lower the voltage to a suitable level for distribution to the consumers. Such a receiving station is known as 'sub-station' If the town is small, having mostly domestic consumers and small industries, a three-phase four-wire system of distribution, as described earlier, would serve the purpose.

For large cities with its fairly heavy industrial consumers, the total load becomes large, and a simple 400V/230V

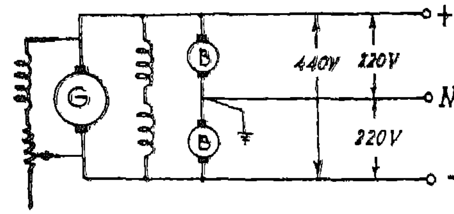


Fig. 6.12. A Rotary Balancer-set

three-phase four-wire system alone is not adequate In such cases there will be both *high-voltage* (HV) and low-voltage (LV) distribution. The low-voltage distribution is the usual 400V/230V system. The high-voltage distribution may be of one or more of 33 KV, 11 KV or 6 KV systems. The high-voltage distribution network is usually a three-phase three-wire system, and interconnects a required number of sub-stations, either by overhead lines or by underground cables. Many large industrial consumers obtain their supply at the high-voltage from the sub-stations These sub-stations, called *secondary sub-stations*, may receive power from another *primary sub-station* which, in turn, receives power from a transmission line. The secondary sub-stations may also receive power from one or more of the local generating stations Fig. 6.13 shows a scheme of high-voltage

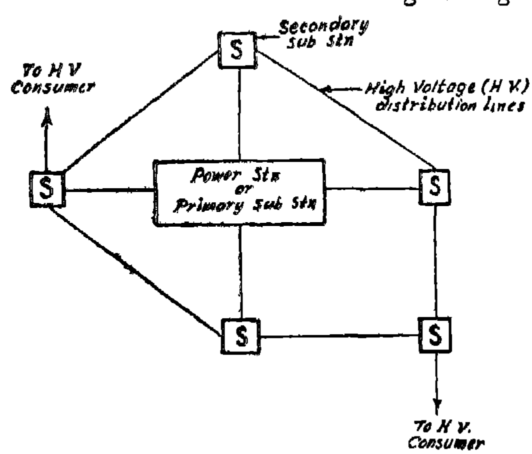


Fig. 6.13. High-voltage Distribution System

distribution system. The whole distribution system is often referred to as the *distribution network*. The HV distribution network encloses the complete area it serves All conductors of the lines are represented by a single line in the diagram, shown in Fig 6 13 and is often referred to as the 'single-line' diagram.

The LV distribution lines, called distributors, are mostly of the overhead line type in areas which are not thickly populated. In city areas with a high density of population, underground distribution lines are preferred. The number of wires on the distribution lines depends upon the load of the area. Usually the wires include three- or six-phase wires for general load, one-phase wire for street lighting, and two neutral wires. Fig 6 14 shows how the distributors are arranged on the poles with the insulators *Pin insulators* are used for straight runs of the line. *Shackle* insulators are used at the point where the line takes a bend or terminates The distributors fall into two categories, namely, *ring distributor and radial distributor*, depending upon whether the distributor *closes in a loop* or *terminates at an end* respectively. In Fig. 6 15, A B C D E F represent a ring distributor and DG represent a radial distributor The small arrows in the figure represent the connections, called *service mains*, to the various consumers. These are tapped from the distributors at the poles. The lines SA, SB, SC, etc., are called feeders. They join the substation S to the points A, B, C, etc, *from which no tapping is made*, because the sub-station feeds the distributor with power at the *feeding points* A, B, C, etc

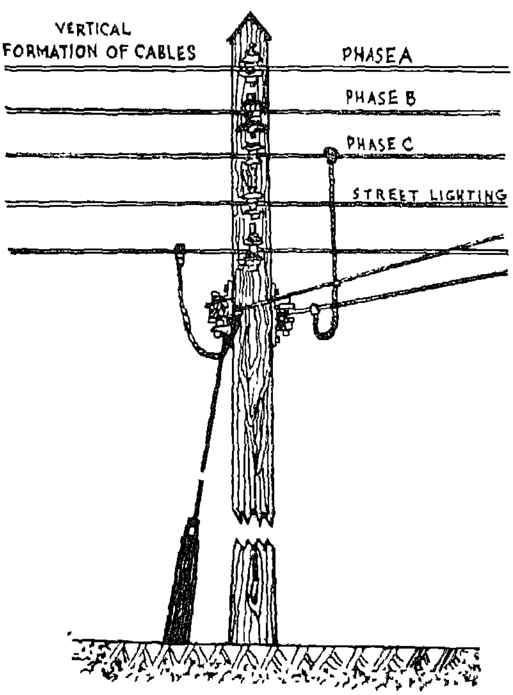


Fig. 6.14. Low-voltage Distributors

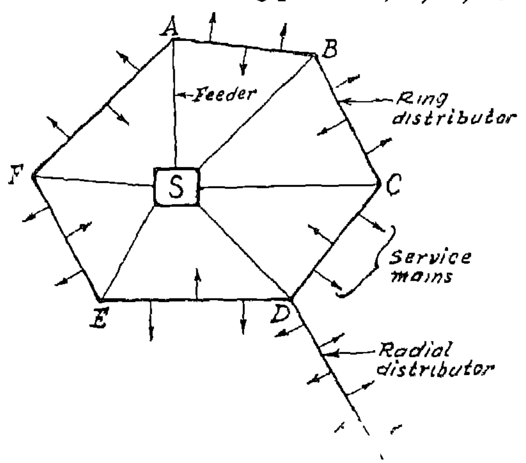


Fig. 6.15. Ring and Radial Schemes of Distribution

The radial distributor is fed at one end only The ring distributor may be fed at one or more feeding points. Even with one feeding point (F), the ring distributor is more reliable than the radial distributor, because if the line snaps for some reason, say, at point K, causing a discontinuity in the distributor, the con-

sumers connected to the ring distributor will continue to get the supply. But under similar conditions, the consumers connected to the radial distributor between K and R will not get any supply. This is shown in Fig 6.16

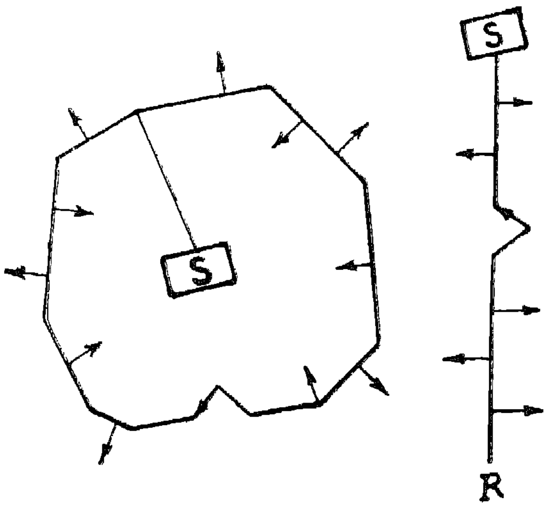


Fig. 6.16. Comparison of Ring and Radial Distributors

When a number of secondary sub-stations S are interconnected by a ring system of feeders, this is known as *ring-main*, as shown in Fig. 6 17

For the purpose of transmission and

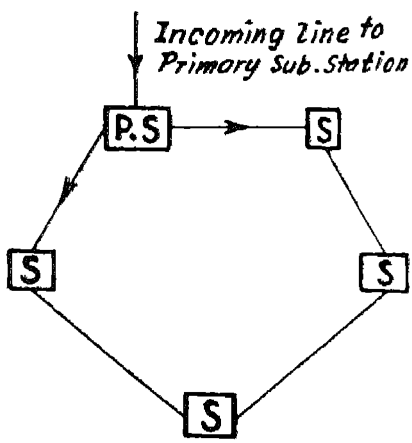


Fig. 6.17. Ring Main System of Feeding Sub-stations

distribution, the different voltage-ranges have been, by convention, given certain limiting values such as the following:

Low-voltage—up to 250 volts
Medium-voltage—above 250 and up to 650 volts.
High-voltage—above 650, and up to 33000 volts.
Extra high-voltage—above 33000 volts.

The size or cross-section of the distributor-conductor is determined by the *permissible limits of voltage-drop* This limit has been fixed by Indian Electricity Rules. The Rules state that the voltage across the terminals of any consumer must be within 5 per cent of the declared voltage of the supply-authority The voltage-drop $v = IR$, and v has a maximum limiting value. For a given current I, v is proportional to the resistance R Since the resistance $R = \rho \frac{l}{a}$, it is inversely proportional to the cross-sectional area 'a' of the conductor for a given length l and a given material (for which is a constant). This means that for given values of v, I, l and p 'a' can be calculated

The cross-section or size of the feeders need not be determined by voltage-drop considerations, because no consumer is supplied from a feeder. Therefore, the cross-section of a feeder is determined by the consideration of the *limit of temperature-rise* which, in turn, depends upon the current in the conductor. Thus, for every cross-section of a conductor there is a maximum current that can be carried safely by it. The *size of the feeders is determined by the current-carrying capacity.*

The cross-section of the neutral conductor is usually half that of the phase

conductors. This is because of the possibility of less current flowing in them compared to the phase-conductors, as the amount of unbalance in the three-phase four-wire system, is very little When the currents in the three-phase conductors are exactly equal and of identical power-factors, the current in the neutral wire will be zero.

The conductors of transmission and distribution lines are erected with some amount of sag in the span between two adjacent supports, to keep the tension on the conductors within a safe limit The tension at the points of support of the conductor is caused by its weight and the pressure of the wind blowing on it. The conductors must be erected on the line to have the minimum safe clearance from the ground. The clearance depends upon the voltage, and is specified by the Indian Electricity Rules, which vary depending upon the nature of the space through which the line passes The clearances are such that normally nothing should touch the phase conductors that endangers life and property.

6-6. Utilization of Electrical Energy

It has been found economical and convenient to use electrical drives for industrial and domestic machinery. They are clean and can be subjected to flexible control. One common example is the diesel-electric traction. Here the diesel engine could have directly driven a locomotive. Actually the diesel engine drives a generator, which supplies electrical power to motors fitted with the axel of the locomotive For ships, the reduction of the shaft length from the engine room to the propeller has been made possible by the use of electric motors. Here the link to the motor, located at the rear and very near to the propeller, is provided by stationary flexible electrical cables. In factories and works, the power room need not be very near the place of actual applications of power to various machines The power room can be located at any other convenient position, from where electrical cables, instead of mechanical shafts, can transmit the necessary power to any desired location.

For *individual drives,* electrical drives are very convenient, as separate motors can be used for various machine parts. This is very difficult to achieve by mechanical devices. In *group-drives,* where a single motor drives many machines, the flexibility of electrical drives can be used to advantage.

The choice of electrical drives depends on many factors Where a group-drive is suitable, a motor of larger capacity would be chosen, and with individual drive a motor of smaller ratings would be used Depending upon the *conditions of service* the motor is selected from the consideration of the way it is enclosed Accordingly the motors may be of the *open type, pipe* or *duct-ventilated type, totally enclosed type* and *flame-proof type* (for use in mines). The *position of the shaft,* whether it is horizontal or vertical, will also affect the selection of motor. The output rating remaining the same, the speed—high or low—will determine the cost of a motor. The *range of speed control* will determine the type of motor and the control-gear. Another important factor is whether *reversal of speed* is necessary or not. The *starting torque* requirement also affects the selection of motor and its starting-gear.

For *domestic applications*, electric motors are used for driving sewing machines, fans, vaccum cleaners, refrigerators, clothes washing machines, etc. They are usually the small universal motors of the series type

In connection with the *machine tools*, it has been found that in large works undertaking mass-production the use of electrically-driven portable tools, such as, drills, spanners, etc., is very economical. The motors are usually of the high-speed type For *lathes, milling and drilling machines*, D.C shunt motors and slip-ring induction motors up to about 30 Kw rating may be used For *planers* a reversing motor is necessary For *punches and shears*, slip-ring induction motors up to about 20 Kw ratings are used together with large flywheel

For *cranes*, D C motors are preferred because of their ability to offer very smooth speed control These are usually of the series and compound types which give high starting torque In A.C., slip-ring induction motors are used.

For *lifts*, D C. compound motors and slip-ring induction motors are used A lift-motor must start and stop easily, and run at moderate speed to give a comfortable acceleration to the passengers

In textile machinery 'constant-speed type' three-phase induction motors are used The motors must be of high efficiency and have good starting torque

For *printing machinery* squirrel-cage motors are used for small machines of constant-speed type. In rotary presses, variable speed slip-ring induction motors are used If the range of speed variation is insufficient D C motors have to be used.

Iron and steel works are the largest single consumer of electrical energy The approximate requirements are 300 Kwh per ton of ingots, and 200 Kwh per ton for rolling The mill motors are mostly of the D C shunt-wound type. Motor having as large as 800 Kw rating may be necessary in some mills

In *electric-traction*, both in the railways and tramways, D.C series motors are used. The most important requirements characteristic of the motors are large starting torque to enable the train to accelerate quickly and large braking torque to make quick stoppage possible

Other fields of utilization are *electric welding* and *induction heating* In welding, electric current raises the temperature of the electrodes to a point where the metals to be jointed can melt Metallic pieces can be heated up to a high temperature, on the principle of electromagnetic induction. A high frequency magnetic field surrounds the metal, and the eddy current induced heats up the metal to the required temperature.

QUESTIONS AND EXERCISES

1 What are the various sources of energy for generating electrical power?

2. What do you understand by the term "calorific value" of a fuel?

3. Show, with the help of a diagram, the various important sections of a steam power plant

4 Explain the functions of the following parts of a steam power plant: (i) economiser, (ii) superheater; (iii) air-preheater, (iv) feed-water heater; (v) forced draught fan; (vi) induced draught fan; (vii) boiler-feed pump; (viii) condensate pump.

5. How is water-power utilized for generating electrical energy?

6 How is electrical power of large magnitude transmitted from one place to another? Give the conventional voltages used for transmission.

7 What types of conductors are used for transmission of electrical power?

8 What kinds of supports and insulators are used in overhead transmission lines?

9. Explain, with diagrams, the method of distribution of electrical power.

10 What are "sub-stations" and what are their functions?

11. Write short notes on the following. (i) neutral conductor; (ii) pin- and shackle-type insulators, (iii) service mains; (iv) feeders and distributors.

12 What limits the cross-sectional area of a distributor?

13. What will determine the cross-sectional area of a feeder-conductor?

14 Name some types of motors, briefly discussing their application in the industry.

CHAPTER 7

Illumination

When the temperature of a body is increased it starts radiating energy in all directions, and this energy radiation is recognized as heat and light by our senses of touch and vision. Heat and light are also considered forms of energy This is known from the fact that heat is produced by rubbing two bodies together This is an example of mechanical work producing heat or, in other words, mechanical energy being converted to heat energy. The temperature of a body can thus be considered to be an index of the heat energy that it contains Let us consider the case of an iron rod heated to a very high temperature in a hot furnace When it is removed from the furnace, anybody around can see the iron in flames for some time, and can see the rod glowing first white hot and then red hot and can feel the heat from a distance throughout the time and until it becomes cool. The heat energy received by the rod in the furnace is radiated partly in the form of light energy and partly heat energy, when kept outside the furnace. The energy radiated as light, expressed as a percentage of the total energy received, is called the radiant efficiency of the body Where the source of light is electricity, heat is produced by passing current through the body

7-1. Definition of Various Terms

A luminous body or a source of light is said to emit *flux of light* or luminous flux which is the energy radiated per second in the form of light. Different sources of light may have different rates of radiation of energy per second This is known as the intensity of the source It is necessary to have some standard or unit which may be used to measure the luminous intensity of the sources of light. This can also be used to know the comparative luminous intensity of the sources. This unit is derived from a candle with a definite size and burning rate. Let a source of *one candle power* (CP) be placed at the centre of a sphere of *one foot* (0.305m) *radius* whose inside surface is being uniformly illuminated by this source. The amount of light received from the source *per unit area* of this surface is the *unit flux* or *Lumen* as it is called. As we know from geometry, the surface-area of a sphere is $4\pi \times (\text{radius})^2$, and in the case considered, it is 4π square foot. Therefore, a source of *1 CP will emit 4π lumens*, and of *2 CP will emit 8π lumens* If the

intensity of the source is uniform in all directions, then the same amount of lumens will be emitted by the source in all directions around it. Thus candle-power is taken as the unit of the luminous intensity of a source A source of light may not usually have equal intensities in all directions. Therefore in general, the candle power of a source of light is always different in different directions.

The degree of illumination of an illuminated surface is the luminous flux per unit area received by it. The British system of this unit is the *foot-candle*. A foot-candle represents the illumination of the inner surface of a sphere of 1 foot radius with a source of 1 CP at its centre.

The efficiency of a source of light may be expressed as the number of lumens per candle power Since the electric lamps receive power in watts, the *efficiency of the lamp is expressed in lumens per watt.* The ratio lumens watt is also called the *specific output* of the lamp.

7-2. The Incandescent Lamp

Fig. 7.1 shows the various parts of an incandescent lamp It consists of a glass bulb and a filament of fine wire made of tungsten metal. When a current is passed through the filament, heat is developed and its temperature rises to an extent where it becomes incandescent or white hot. The light emitted by the incandescent lamp is the glow of this white-hot filament. The air, which contains oxygen, is removed from the bulb before it is sealed, because the oxygen will burn out the filament. To increase the life of the filament, some inert gas, like a mixture of nitrogen and argon gas, is placed inside the bulb That is why the incandescent lamp is also called the *gas-filled lamp*.

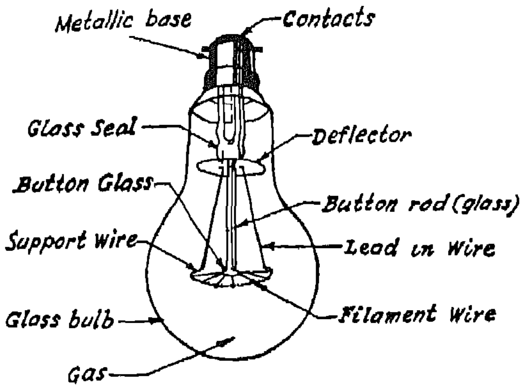


Fig. 7.1. An Incandescent Lamp

The size of an incandescent lamp is given in *watts*. The larger the wattage rating, the higher will be the rate of heat produced, and more will be the light emitted per second. The base of the lamp, made of brass, fits itself in a holder. The holder has two slots diametrically opposite to each other, shaped at right angles, as shown in Fig. 7.2

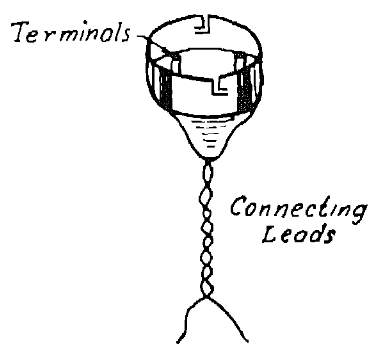


Fig. 7.2. The Holder of an Incandescent Lamp

The two pins on the sides of the bulb-base get locked in the slots, and in this position the two terminals of the holder connect the two contact points at the bottom of the base of the bulb Another

type of base is the screwed type in which the holder is also threaded, so that the bulb can be screwed in the holders. In this case, one terminal of the bulb is connected to the screwed base, while the other is connected to a contact-point at the bottom of the bulb.

The incandescent lamps may be of small wattage for use in torch-lights at 1.5 volts or 3 volts Lamps of larger wattage up to 300 watts are also available; they are made for use to 230 volts Since the lamp has only resistance, its power factor is unity, and as such a given incandescent lamp will take the same watts with D C or A C supplies

7-3. The Fluorescent Lamp

The fluorescent lamp consists of a glass tube with one filament-electrode sealed into each of its two ends These filaments are made of coils of fine tungsten wire and they are coated with a substance which can emit or release electrons. The inner surface of the tube is coated with a thin layer of a phosphor substance. The tube is filled with argon gas along with a drop of mercury.

The lamp-circuit is shown in Fig 7.3 As distinguished from the incandescent lamp, this lamp needs for its operation two additional devices, the *starter* and the *ballast* The starter acts as a switch, which gets opened automatically when heated to a certain temperature. The ballast is a coil of insulated wire wound round an iron core. The connections are made as shown in the figure. When the supply is switched on, a current passes through the circuit comprising the two filament electrodes, the starter and the ballast in series, and the filament electrodes get heated owing to the passage of current. The heat vaporizes the mercury and electrons emit from the substance with which the filaments are coated. This current also heats the thermostat of the starter which opens the series circuit after a few seconds As soon as the starter disconnects the circuit, the current is stopped

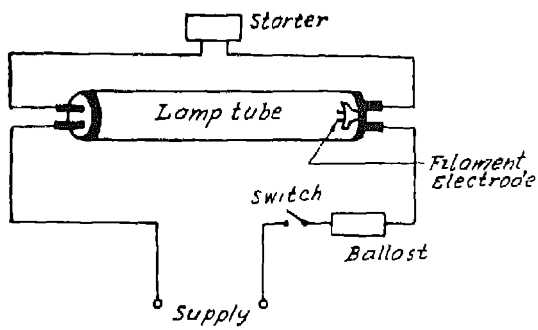


Fig. 7.3. A Fluorescent Lamp

This sudden stoppage of current produces in the ballast a large e.m.f. of self induction of nearly a thousand volts lasting only for one or two seconds This high voltage starts the flow of electrons from one filament to the other As electrons flow through the lamp tube, they collide with the atoms of mercury. These collisions produce invisible ultraviolet light The ultra-violet light strikes the phosphor substance on the inside surface of the tube. As a result of this the phosphor *fluoresces*, or glows, and the tube emits light that is very nearly the same as daylight The process by which the light energy is obtained in this lamp is seen to be quite different from the one required for the incandescent lamp and a low pressure is essential inside the tube for all the

fluorescent lamps. The fluorescent lamp is very extensively used, because heat energy radiated is much less when compared to that of the incandescent lamp As a result, it not only keeps the room cooler but also gives out about three times the light of an incandescent lamp for the same wattage.

7-4. The Mercury-Discharge Lamp

The mercury-discharge lamp, shown in Fig 7 4, consists of two glass tubes, one inside the other The inner tube is made of hard glass or quartz because of the high temperature of the arc and high pressure of the mercury vapour. The vapour pressure is about two to three atmospheres There is a smaller auxiliary electrode, called the starting electrode, for initiating arc. A current limiting resistance is put in series with this electrode, of the order of 50,000 ohms, to limit the current to a very low value. At the base one electrode is connected to the screwed metallic part while the other is connected to the contact point.

When the lamp is connected to the supply, a small current flows through starting electrode and a small arc is formed between this and one main electrode. At the same time full voltage exists across the main electrodes, and the arc almost immediately moves from the starting electrode and bridges the main electrodes. The initial light emission is very small, because it takes some time for the condensed mercury to vaporize through the heat of the arc. It takes the lamp about seven to eight minutes to become fully bright The colour of the light emitted is not very white but a little bluish.

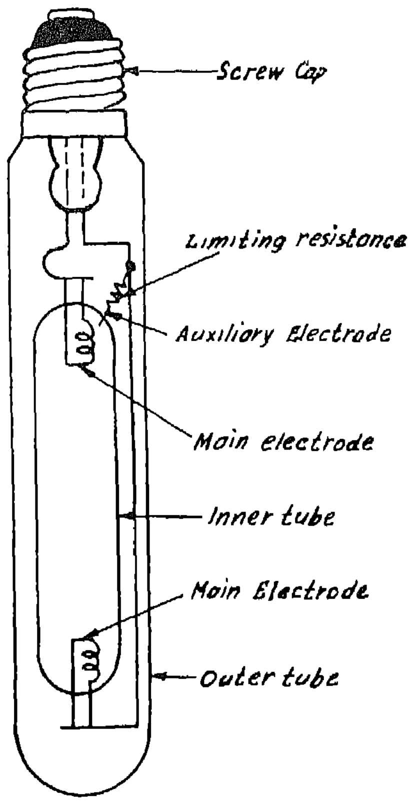


Fig. 7.4. A Mercury-Discharge Lamp

7-5. Arc Lamps

If a current is passed through a contact of two pieces of conducting material, an arc can be observed at the moment the contact is separated by small gap. The current continues to flow through the gap in air in the form of an arc, if the gap is small and the voltage-drop across the arc is sufficient to maintain it. This process is utilized in the arc lamp in which a current flows between two electrodes which are drawn apart. The arc, thus produced, serves as a very efficient source of light. There are various forms of such lamps like a carbon arc, a metallic electrode arc, etc

The Carbon Arc lamp is the earliest type and is still used. The arc consists of carbon vapour and is surrounded by an orange-red zone of burning carbon and pale-green flames. A D.C supply is connected across the two carbon electrodes. A crater is formed in the tip of the positive electrode, as shown in Fig 7 5(a), which is the white-hot spot and emits 85 per cent of the light given by this type of lamp The temperature of the arc is about 4000°C which is really very high. The arc gives out about nine lumens per watt. A definite voltage has to be maintained across the arc for a given length. As the arc continues to operate, the tip of the positive electrode gradually burns out, and the length of the arc increases. This will result in a decrease in the intensity of illumination, unless some arrangement is made to adjust the position of the electrodes to maintain a constant gap. Fig. 7.5(b) shows an automatic mechanism for keeping the arc-length constant. The negative carbon electrode A is fixed, and the positive carbon electrode B is connected to a plunger C of the solenoid coils D_1 and D_2. The core or plunger C is movable. The magnetic field produced by the coil D_1 attracts the plunger C upwards against the force of gravity. A constant current flows through the coil D_2 in such a way as to act on the plunger in the direction opposite to that in which the current in D_1 acts. Before an arc is struck, the two carbon electrodes are in contact. Now when the supply is switched on, a large current flows through D_1 and exerts a force which separates the electrodes A position of equilibrium is reached, for which, the force due to current flowing in D_1 is equal to the sum of the forces due to the gravity and due to the current flowing in D_2. As the carbon in the positive electrode burns out with continuous use, the resistance of the arc increases because of the increase in arc-length, and the current in the arc, and hence in D_1, decreases. This will decrease the magnetizing force by the coil D_1 and will not be able to hold the positive electrode against the opposite forces. Thus the coil D_1 allows the plunger C to come down by such distance as to have more current again to hold the electrode. Since the opposing forces are constant, the force necessary to hold the electrode also must be constant. Therefore, to fulfil this condition the current in D_1 and hence the length of the arc should become the same as at the beginning when the arc was struck This explains how the arc length is automatically kept constant. Usually a resistance is connected in series with the arc to keep it stable, as it has been observed that the arc tends to become unstable when current changes in the circuit Such types of arc lamps are used in cinema houses for projection of films on the screen.

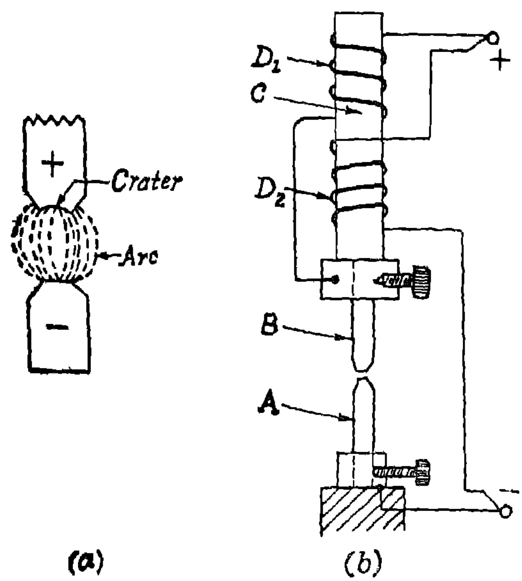


Fig. 7.5. A Carbon Arc Lamp

QUESTIONS AND EXERCISES

1. Define the following terms.
(i) flux of light, (ii) intensity of a source of light; (iii) candle-power; (iv) lumen; (v) foot-candle

2 What do you mean by the "efficiency of a lamp"?

3 Describe, with sketches, a tungsten filament lamp. Why is it also known as "gas-filled" lamp?

4. Explain, with diagrams, the working principle of a fluorescent-tube lamp.

5. What is a mercury-discharge lamp and how does it work?

6. Describe, with diagram, a carbon arc lamp and indicate the field of its application How is the length of the arc controlled automtaically?

CHAPTER 8

Activities

CONDUCTORS of electricity may be of the following types:

(a) Bare Copper·

- (i) Hard-drawn bare copper conductors—solid
- (ii) Hard-drawn bare copper conductors—stranded
- (iii) Hard-drawn copper conductors—cotton braided
- (iv) Hard-drawn bare cadmium copper conductors
- (v) Annealed bare copper binding wires
- (vi) Annealed tinned copper binding wires
- (vii) Annealed bare copper strips
- (viii) Bare and enamelled copper aerial wires

(b) Winding Wires:

- (i) Single and double cotton covered wires
- (ii) Silk and rayon covered wires
- (iii) Cotton and paper covered wires
- (iv) Cotton and paper covered strips
- (v) Oleo-resinous enamel covered wires
- (vi) Synthetic enamel covered wires

(c) Aluminium:

Aluminium conductors steel reinforced

(d) Cables:

- (i) VIR insulated cables—taped, braided and compounded
- (ii) VIR insulated cables—tough rubber sheathed
- (iii) VIR insulated cables—lead alloy sheathed
- (iv) VIR insulated cables—weather proof compounded
- (v) VIR insulated cables—flame proof compounded
- vi) Motor car ignition cables
- (vii) Bell and telephone wires
- (viii) Flexible lift cables and mining cables
- (ix) Aerial cables
- (x) Railway inter-vehicular coupler cables
- (xi) Trailing cables
- (xii) Arc-welding cables

8-1. Study of Conductors and Cables

The wires and cables may have single or multiple cores (conductors) For multiple core cables, each core is insulated from the other.

A length of about 10 cm may be cut away from each variety mentioned above, and the following features be studied

(A) Physical appearance and colour of the bare conductors, pattern and arrangement of bare stranded conductors.

(B) For insulated conductors, the material, shape and number of the conductor; and the various layers of insulation and other coverings

The insulation and coverings may be peeled off in steps, as shown in Fig 8.1, over a length of 1 cm. for each step in order that the physical appearance, thickness, and colour of the coverings and insulation may be seen

Each sample of the conductors may then be sketched in a note-book, and the descriptions, based on observation, may be noted. Alternatively, each sample may be mounted on a wooden board in a row by means of clips and the particulars of the corresponding cable labelled against each on the board

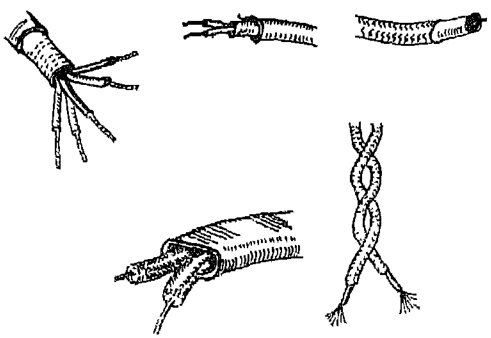


Fig. 8.1. Conductors and Cables

8-2. Determining the Gauge of the Conductors or Wires

The diameter of round wire is measured with a gauge called the *Standard Wire-gauge* It measures the diameter of a conductor according to a *standard* gauge number, as shown in Fig. 8 2. The wire-gauge has openings or slots, by means of which the correct wire size is determined These slots are numbered to indicate wire-gauge sizes from 0 to 40, each number representing a particular wire-size The larger the number, the smaller is the diameter of the wire

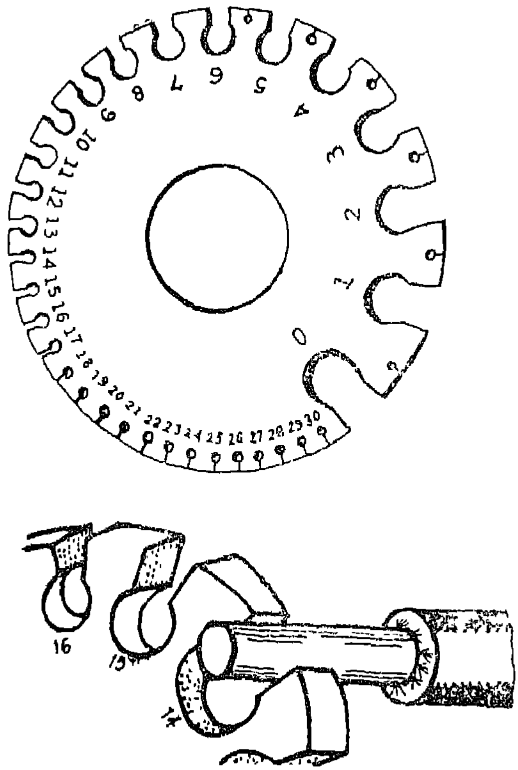


Fig. 8.2. Determination of Conductor Size by a Wire-gauge

This is how the size is measured with a wire-gauge:

(1) Insulation and all foreign material, over a length of 1 cm. from the end of the wire to be measured, are removed. If it is a bare wire, it is cleaned and the surface is made smooth.

(2) The bare wire is placed in a slot of the wire gauge

(3) The wire is tested in the various slots until it fits well into one of them It should not be tight

(4) The gauge number of this slot on the face of the gauge is read, and the wire-size determined

8-3. Study of Insulating Materials for Armature Winding

The insulating materials have been classified according to the limitations of temperature·

Class A insulation consists of

(i) cotton, silk and paper when impregnated with, or immersed in some insulating liquid;

(ii) moulded and laminated materials with cellulose filler and resins;

(iii) films and other cellulose products; and

(iv) varnishes and enamel applied to conductors

Class B insulation consists of mica, asbestos, fibre glass in built-up form with organic building substances.

Class H insulation consists of

(i) mica, asbestos, fibre glass in built-up form with silicon compounds; and

(ii) silicon compounds in rubber or in resinous form

Micanite comprises thin flakes of mica cemented together with shellac varnish. It is made in sheets

Moulding Micanite is bonded with hard varnish which softens when heated, and hardens when cooled again. This enables the substance to retain the shape which gets moulded when hot. For the lining of the slots of the armature flexible micanite is used.

Insulating tapes are made of cotton or linen coated with some insulating oil These are also known as 'empire' tapes or cloths.

Insulating papers are papers treated with insulating varnish. Thick papers or boards used for insulating purposes have various names· Press-spahn, Fuller board, Press board, etc These are used for slot linings, for insulating washers on field coils and for similar purposes

Leatheroid, or *leather paper*, or *fish paper* is a very tough form of paper product, used as a slot lining material.

Fibre or Vulcanized Fibre is very similar to leatheroid and is used for slot wedges.

Mica-cloth and Mica-tapes are made from cotton or silk fabrics interwoven with mica.

Samples of all the insulating materials, mentioned above, may be collected and their physical appearance, colour and other descriptions may be studied and noted.

8-4. Studying the Effects of Magnetism by Constructing an Electro-magnet

The materials required are.

Soft-iron rod, with 2.5 cm. diameter and 15 cm. long, a 10 m. long piece of No. 30 SCC (single cotton covered) magnetic-wire (because these are used for winding electro-magnets), 2 dry cells of about 1.2 volts each, magnetic compass, single-contact push-botton switch,

small pieces of hard steel and soft-iron and some small nails.

The tools required are:

Side-cutting pliers and knife.

Procedure:

(i) A piece of wire, about 1 m long, is connected, as shown in Fig 8.3, and kept along the north-south direction

(ii) The magnetic compass is placed under the wire, as shown. The push-botton switch is pressed

(iii) The direction in which the compass-needle turns is noted The direction of the deflection may be checked by applying the 'Cork-screw Rule'

(iv) The magnet wire is now wound around the soft-iron rod, and about 30 cm. of wire from each end is connected to the battery. This now becomes an electro-magnet.

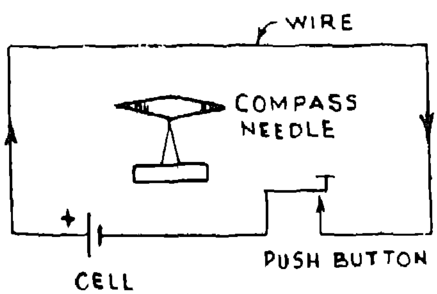


Fig. 8.3. A Compass Needle near a Current-carrying Conductor

(v) The electro-magnet is brought near the compass needle, as shown in Fig. 8-4. The polarity of the needle nearest to the core is noted. We know from the laws of attraction that the end of the core must have the opposite polarity. In this way, the polarity of the magnetic core can be determined.

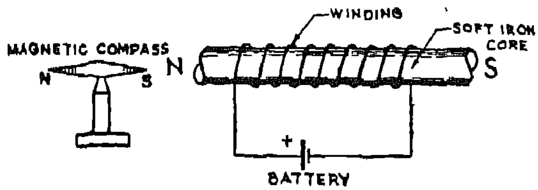


Fig. 8.4. A Compass Needle near the Pole of an Electro-magnet

(vi) If the battery connection is reversed, current through the coil will flow in the opposite direction, and polarities opposite to those in the case of (v) will be produced. This can be checked with the magnetic needle.

The polarities of the electro-magnet, according to the direction of current, as given in chapter 2, may be checked through the experiments of (v) and (vi).

(vii) The electro-magnet, with one cell connected to the winding, is now allowed to pick up some nails. The number of nails is noted down. Next, two cells in series are connected to the exciting coil In this condition again some nails are attracted by the magnet-core It will be noticed that the number of nails has increased now This proves that doubling the voltage in the circuit has doubled the current which, in turn, has doubled the ampere-turns (MMF), because the number of turns has remained the same. The increased ampere-turns have increased the magnetic field strength and so, more nails have been attracted. The same result may be obtained by doubling the number of turns and keeping the value of the current the same.

(viii) If the soft-iron core is now removed, and is replaced by a hard steel rod and the battery is connected to the coil, this too will attract some nails. If the battery is now disconnected, some nails will still be attracted by the core. Now if the compass is placed near the core, it will show the same polarity as it had during the current flow. This shows that the hard-steel has been able to retain some amount of magnetism acquired during current flow Thus even if the current is absent, it behaves like a magnet and hence has been called Permanent Magnet.

8-5. Study of the Pattern of Magnetic Field

Materials required ·

A horse-shoe magnet, a bar-magnet, a solenoid, some No 12 SCC wire. card-boards, iron-filings, a dry cell of 1 2 V, a rheostat of 25 ohms, a compass needle and a push-button switch.

Tools required are·

Cutting-pliers, knife and a pair of scissors for cutting the board

Procedure:

The magnets, solenoid, and a piece of current-carrying wire are arranged and mounted, as shown in Figs 8 5(a), (b), (c) and (d). Iron filings are sprinkled on the card-boards. It will be noticed in each case that the iron-filings will line-up in a definite symmetrical formation. This gives the pattern of the magnetic field in each case. The polarities can be noted by the compass needle The field pattern, in each case, may now be sketched in a note-book and checked with reference to the patterns given in chapter 2.

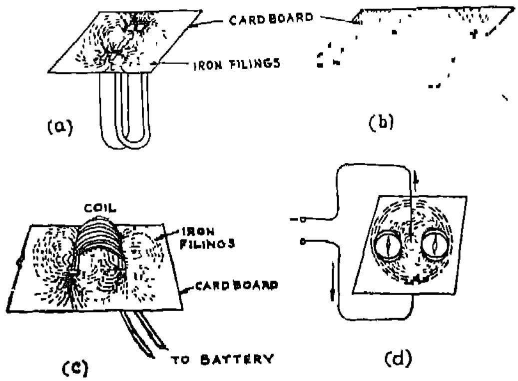


Fig. 8.5. Patterns of Magnetic Field

8-6. Constructing a Buzzer

Materials required:

Two pieces of sheet metal, three pieces of band-iron, about 15 m. of gauge No 26 magnet wire, one piece of spring sheet brass, one piece of masonite or bakelite or plastic, two solder lugs, screws and hexagonal nuts, one piece of soft-iron rod of about 0 5cm in diameter and 3.5 cm. in length, two flat fibre washers and one shoulder-type fibre washer.

Tools needed·

Cutting pliers, knife, screw-driver, soldering iron, hand-drill, small hammer and bench-vice

Procedure:

Assemble the various parts, as shown in the sketch in Fig 8 6. The exciting coil terminals are connected to a battery of 6 volts (rheostat may be used in series to limit the current to the specified safe value for the wire). The setting of the contact-point screw is adjusted to obtain the minimum sparking between the screw and the contact strip.

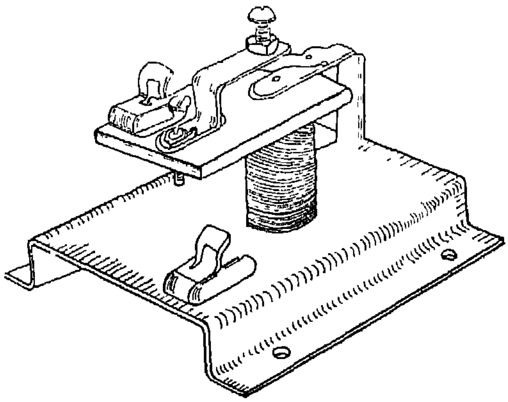


Fig. 8.6. Construction of a Buzzer

The tone of the buzzer can be changed by changing the setting of the contact-point screw.

8-7. Study of Electrical Machines

(a) Study of the Laws of Induced EMF· The materials required are A wooden bobbin of about 10 cm in diameter and of 3 cm. in width, about 10 m. of gauge No. 30 SCC wire, a galvanometer, and a bar-magnet

Procedure:

(i) The bobbin is first wound with a certain number of turns, say, with 5 m of the wire, and the ends of the wire are connected to the two terminals of the galvanometer, as shown in Fig 8 7

(ii) The magnet is now brought towards the centre of the coil rather slowly, and the number of divisions of the deflection is noted down. When the movement of the magnet, relative to the coil, ceases, the galvanometer reads zero

(iii) If the magnet is moved away from the coil at the same speed as in (ii), the galvanometer will deflect in the opposite direction, but the number of divisions deflected will be more or less the same as in (ii).

(iv) Now, the magnet is moved faster, relative to the coil, and a larger deflection will be obtained.

(v) The remaining length of 5 m of the wire is now wound in the bobbin, and the operations of (ii) and (iii) are repeated. It may be observed that with the same speed of the magnet's movement the deflection of the galvanometer almost doubles.

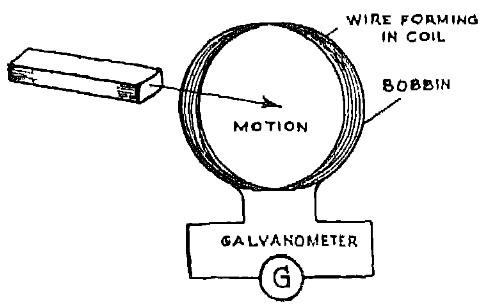


Fig. 8.7. A Bar-magnet Inducing Voltage in a Coil

Faraday's Laws of Electromagnetic Induction, as given in chapter 3, may be verified through the above-mentioned observations. The observations may be recorded in a note-book.

The experiments may also be conducted by bringing another identical coil excited by a battery, and placed near the coil connected to the galvanometer. With the switching 'on' and 'off' of the battery, the galvanometer will deflect in the opposite directions.

(b) Study of the generator principle·

A straight conductor, with its ends connected to a 'centre-zero' galvanometer, is moved across the gap between the poles of a horse-shoe magnet, as shown in Fig 8.8 The following features may be observed:

(i) The conductor is moved out of the pole-region of the magnet and the direction of the deflection is noted in the galvanometer

(ii) The conductor is now moved into the region under the pole, the direction of the deflection would be in the way opposite to that of (i)

(iii) In the cases of both (i) and (ii), the deflection will be larger if the movement of the conductor is quicker

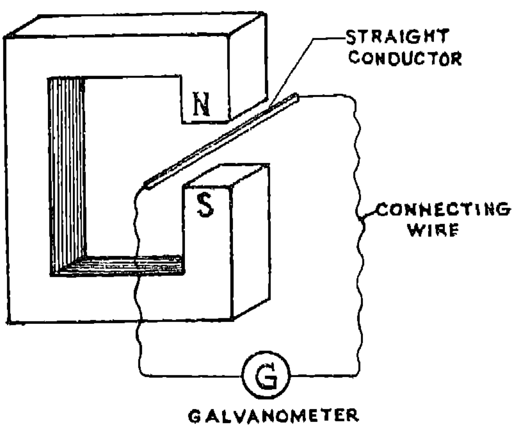


Fig. 8.8. Demonstrating Generator-principle

In an actual D.C generator, the conductors of armature are rotated by a prime-mover. For a given strength of the magnetic field, the higher the speed the larger will be the induced EMF.

(c) Study of the principle of motor-action:

A sliding thin conductor AB is placed on two current-conducting strips C and D The whole arrangement is now placed in the gap between the poles of a magnet, as shown in Fig 8 9 The strips C and D are connected to a battery through a rheostat, a zero-centre ammeter and a reversing switch.

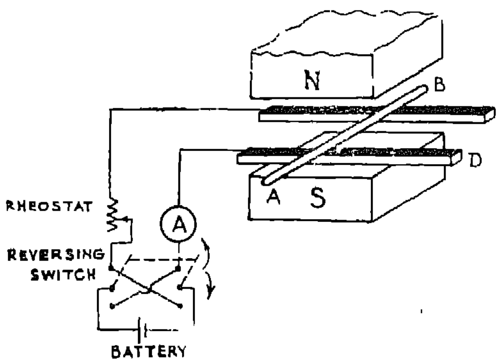


Fig. 8 9. Demonstrating Motor-principle

We may observe the following by closing the switch:

(i) A larger value of the resistance is included in the circuit by the rheostat adjustment. The reversing switch is now closed in one direction. As soon as the current passes through AB through the sliding contacts with C and D, the conductor will be seen to slide across the gap at a certain speed. After a little movement of the conductor, the switch is put off and the current-flow is stopped.

(ii) Now the switch is put on in the other direction. The conductor AB will now be seen to move in the direction opposite

to that in (i) but at the same speed.

(iii) The value of the current can now be increased by decreasing a part of the resistance of the rheostat, and the experiments of (i) and (ii) may be repeated It may be observed that the speed of movement in either direction now increases.

(iv) If the surfaces of the rod AB, and also of the strips C and D, are polished so that the friction between the rod and the strips become less, it may be observed that with the current remaining the same, the rod travels at a higher speed

From all the above observations, Fleming's Left Hand Rule may be verified In an actual motor, the conductors, like AB, are in the slots of the armature, to which the current is supplied through the commutator from the brushes, which, in turn, are connected to the supply mains The magnetic field is provided by the poles of the motor, excited by the field coils

(d) Study of the construction of a D C. Machine

The following parts of a D.C. Machine may be studied and sketches and details noted down.

(i) Pole-cores and pole-shoes, field coils and their connections; the method of fitting of the poles with the stator frame;

(ii) The armature-spider and its fitting to the shaft;

(iii) The armature-core built-up from the sheet-steel stampings, and the slot-shapes,

(iv) The armature-coils and the method of putting the coils in the slots;

(v) The commutator and its fitting on the shaft by the side of the armature;

(vi) The connections of the coil-ends to the commutator-risers, along with the process of soldering;

(vii) The brush-gear, their interconnection and bringing out of the armature terminals;

(viii) The terminal-box and the terminal markings and the connection of the terminals to the switch-board.

(e) Study of the construction of A.C Machines like A.C generator and Induction motors.

Various parts of the stator and rotor may be studied with the method of their fitting. Sketches and descriptions may be recorded in a note-book

(f) Study of a Power Transformer.

A small transformer may be made by having (i) a core made of rectangular stampings and (ii) two coils made of DCC (double cotton covered) wires, mounted on the two limbs of the core One coil may have double the number of turns in the other By applying a very low A C voltage across one coil, the voltage across the other coil can be measured and the 'transformation ratio obtained' By connecting a load resistance on the secondary side, primary and secondary current can be measured.

8-8. Study of Various Types of Switches

Types of switches·

(i) Knife-blade switches—
  (a) Single pole, double pole, three pole
  (b) Single throw, double throw.
(ii) Snap-switches—
  (a) Single pole, double pole, three-way
  (b) Four-way, electrolier.
(iii) Flush-type wall switches—
  (a) Toggle and push-button, single pole.
  (b) Double pole three- and four-way.

Knife-switch

This is mostly used in power-circuit installations and can be with or without fuse The switch is made of copper blades mounted on a copper hinge and a copper clip for the blades to make contact Fig 8 10 shows a type of knife-switch used on switch-boards with all live parts exposed

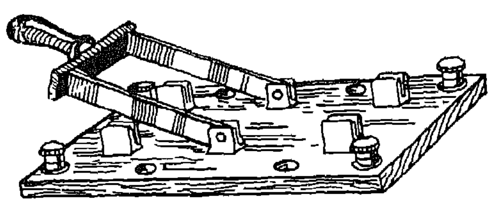


Fig. 5.10. A Knife-switch

Snap-switch

This type is constructed with rotary blades which, when turned, cause tension on a spring. This tension makes the blade snap quickly into the contact clips. It is mounted on a slotted or a solid porcelain base, as shown in Fig 8 11 This switch is suitable for surface mounting and may be used also for conduit wiring. These switches are mostly used for currents up to 20 amps and 250 volts.

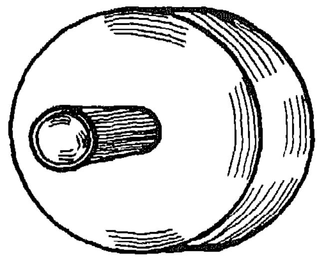


Fig. 8.11. A Snap-switch

Flush-switch

Fig 8 12 shows a flush-type switch This is so named because it is made to fit into the wall and be in flush with the wall surface. The only part extending beyond the surface are the push-buttons or toggle lever. The operating mechanisms of all flush switches are mounted on porcelain boxes with mounting ears for fastening in the wall These switches are available for current up to 20 amps and for a voltage of 250 volts.

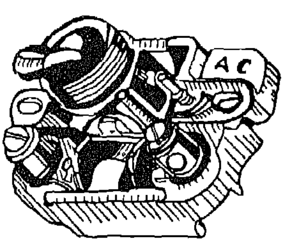


Fig. 8.12. A Flush-switch

The construction and operating mechanisms of switches of various types may be studied and the respective

sketches and descriptions recorded in a note-book.

8-9. Installation of Light Controlled by Two Three-way Switches and One Four-way Switch

To wire and connect a lamp to be controlled from three points, two three-way and one four-way switches are to be used A three-way switch is nothing a but a two-way switch with two points in the sketch linked together A four-way switch is the same as the 'intermediate switch' described in the preceding chapter

The four-way switches are generally used, along with three-way switches, at the two ends This circuit is used to control lights from three or more points. If a light is to be controlled from five-points, we would require two three-way switches at the two end points and three four-way switches in intermediate positions.

The wiring is made according to the connection diagram of Fig 8.13. The positions of the switches A, B and C show that in A points 1 and 4, in C points 1 and 4, and in B points 1 and 2 and also 3 and 4 are connected. If the knobs of these switches are turned once, the connections will change thus in A points 2 and 3, in C points 2 and 3, in B points 1 and 3 and also 2 and 4 After the completion of the wiring, the circuit is connected to the supply as shown. Now by operating all the switches, the working of the arrangement can be checked.

The circuit may be tested, as described above, and connection diagrams, sketches and other descriptions may be recorded in a note-book.

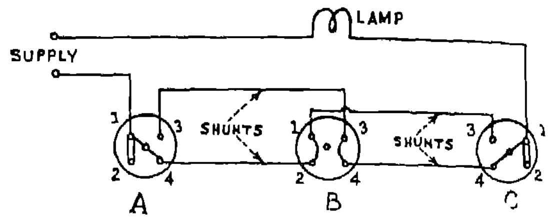


Fig. 8.13. Connection Diagram of Four-way Switches

8-10. Installation of an Electrolier Switch

To connect and wire three sets of light, to be controlled from a three-circuit electrolier switch

Electrolier switches are used to control a number of lights on chandeliers and also to control various coloured lamps from one switch Moreover, this switch can be used to get different heat outputs from an electrical stove.

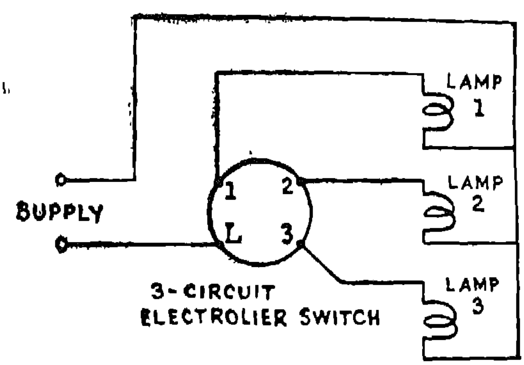


Fig. 8.14. Connection Diagram of Electrolier Switch

The wiring is done according to the circuit diagram of Fig. 8.14. After the wiring is over, the supply is connected to the points shown in the figure. The contacts of the switch are marked L—1—2—3. On the first turn of the switch, the rotary blades connect L with contact 1 and light lamp 1. The second turn connects L with contacts 1—2 and lights the lamps 1 and 2. The third turn connects L with contacts

1—2—3, and lights all three lamps 1, 2 and 3. The fourth turn disconnects L from contacts 1, 2 and 3 and all lamps go 'off' Then the whole operation repeats itself with subsequent turns.

The performance of the circuit may be tested by operating the switch. Connection diagrams and sketches of the switch and other descriptions may be recorded in a note-book

8-11. Wiring by 'Tree System' and 'Loop-in System'

Wiring and connecting two lamps of a sub-circuit, each controlled by a switch, are to be done by (i) Tree system, and (ii) Loop-in system

The first system requires joint or junction boxes, while the second system does not need them. Any of the wiring methods, described in chapter 5, may be used, depending on its suitability in the case in question. The materials required will depend on the system of wiring and the dimensions of the room, and can be estimated easily when all particulars are known.

Fig. 8.15(a) shows the 'Tree system', and Fig. 8 15(b) the 'Loop-in system' of connections. It may be seen from the connection diagram, that two joints are necessary in the first method, while none are in the second method. But the second method will need, for a given run, more wire, both in length and in number

To do more exercises, the wiring of the two schemes mentioned above may be done by each of the wiring systems given in chapter 5.

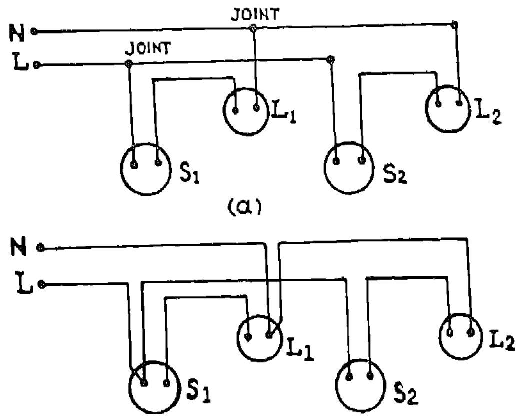


Fig. 8.15. Wiring with Joints and 'Loop-in' Connections

8-12. Wiring for a Shop

It is required to wire and connect four lamp-points, each to be controlled by a separate switch. A conduit system will be adopted in this case, and the wiring will be done by the 'Loop-in' method, as shown in Fig 8.16.

A and G are 'inspection elbows', B, C, D, E and F are 'inspection tees'. The wiring is done according to the rules given in chapter 5, and connections are made as given in Fig. 8 16 S_1, S_2, S_3 and S_4 are switches for lamps L_1, L_2, L_3 and L_4 respectively. After the completion of the wiring, necessary insulation tests are made, as explained in chapter 5. If the circuits are all right, the main-switch may be put on, and other switches operated, to test the proper working of the lamps.

8-13. Repair of Various Domestic Appliances

Repairing the domestic apparatus mostly involves

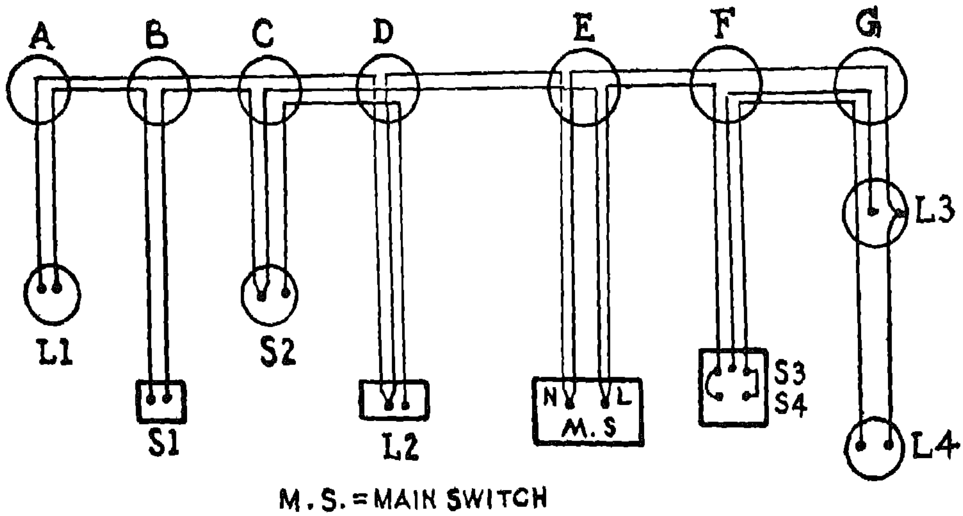


Fig. 8.16. Wiring Diagram for a Shop

(i) loose and dirty connections;
(ii) frayed and broken flexible conductors;
(iii) breakage of elements and
(iv) insulating portions cracking, burning out or peeling off.

Switches

While undertaking the repair of switches the following parts must be carefully tested:

(a) terminals, (b) contact springs, (c) bolts holding the central parts and (d) fixing screws

The ends of the wires should be examined to see if the loop-feed is tightly joined The terminals of switches become loose through frequent jarring. This may result in the flickering of the lamp, followed by a total failure of the switch. Tightening a terminal too much may result in injury to the conductor, and the wire may drop away from the terminal. All conductors of a thin section should be doubled before placing them in terminals. The contacts of the switches may become loose and make poor contact with the springs Necessary adjustments may be made to rectify this. Small bolts holding the mechanism of the switch may become loose, in which case the switch should be removed and the bolts tightened from the back If corrosion occurs in the switch terminals, the contact points must be cleaned To prevent leakage from the switch terminals through the cotton braiding of the wire, the latter must be cut back over a certain portion from the end of the wire.

Table Lamp

For a table lamp, the possible places of failure are (a) the socket-outlet and the plug to which the flexible chord is connected from the table lamp, (b) in the chord itself due to discontinuity, (c) in the lamp-holder and (d) the switch at the lamp base.

Whether proper contact is taking place in the socket-outlet may be checked by a test lamp connected to the plug, after disconnecting the table lamp chord It may be necessary to tighten and clean the contacts of the socket and the pins of the plug to remove the defect, if any The ends of chord in the lamp-holder become brittle and get disconnected. The springs of the holder pins also may be checked to ensure a proper contact with the bulb-terminals. The switch of the table lamp, too, should be checked By checking all these parts, mentioned above, and with the necessary replacements, a table lamp may be brought back to working condition.

Fan

A fan, whether ceiling or table, must first of all be disconnected. For D.C. fans the defects may be due to (i) discontinuity of the circuit, (ii) short-circuit between turns of the armature winding, (iii) wearing out of commutator segments and brushes and dirts in them, (iv) open or short-circuits in the field winding and (v) failure of insulation due to dampness or its having been burnt.

The continuity may be tested by means of a buzzer, a bell or a lamp in series with the circuit and applying the required voltage of the buzzer, etc., or by a meggar. After locating the fault, the winding circuit may be rectified. Short-circuits in the armature may be tested by applying a low voltage across the brushes and measuring the voltage between every two adjacent commutator segments. For a short-circuited coil, the voltage will be nearly zero. The commutator may be rectified by turning it in a lathe and under-cutting the mica, to leave a gap with a small depth in between two segments, so that the brushes may slide smoothly with the rotation of armature. All dirt must be removed and the end of the brush connecting commutator segments must be properly shaped to give a good contact. The tension of the brush-springs should be checked to obtain correct brush pressure on the commutator. The open-circuit of the field winding is checked in the same way as that of rectifying the armature and the winding. The short-circuit is detected by measuring the resistance, it is indicated by a low resistance. The field coils might have to be removed. The insulation resistance of the windings may be determined by a meggar. If found low, the windings may be dried in a hot-box and provided with an insulating varnish. If the insulation is damaged beyond repair, the armature or field windings may have to be rewound.

For A.C. fans, the most common defect encountered is the failure of the capacitor used for starting purposes This means that the fan does not rotate. The capacitor may be tested for insulation and if found low it should be replaced. Defects in the windings may be in the nature of open circuit and short-circuit. These are detected by a continuity tester and by a resistance test. If the defect is a major one, the armature may have to be rewound. Since there is no commutator in A.C. fans, troubles are not as many as in a D.C. fan.

Electric Iron

The defects with electric irons mostly lie in the socket-outlets, plugs, the

chord and the connecting socket into which the pins on the iron fit. The wear caused in an electric iron connector is very severe because of the movement and high temperature. The chord is usually a three-core flexible wire, one core being used for earthing. The connector is supplied with an earthing contact connecting the earth wire to the body of the iron The chord is fitted with a three-pin plug head. A continuity test is done for the three cores of the chord. Tests for short-circuits should be made between the cores, taking two at a time One should have a continuity test between the terminals to ascertain whether the heating element inside is broken Insulation of the terminals and the heating element from the body of the iron should be tested to determine if there is any direct contact with the body of the parts which are supposed to be 'live' when energised from the supply.

After detecting the defects, the necessary repair can be done easily. This may involve replacing the chords and other parts by new ones, or rectifying the insulation at the affected points.

Electric Toaster and Stove

These domestic appliances also can be tested in the manner shown in the case of electric iron and the defects rectified accordingly.

8-14. Measurement of Resistance

Two important methods of measuring resistance are (i) by Wheatstone Bridge and (ii) by Ammeter and Voltmeter.

Wheatstone Bridge

The Wheatstone Bridge, as shown in Fig. 8 17, consists of four resistances, of which R_1 and R_2 are fixed known values selected and arranged on two resistance boxes. R is a resistance box the value of which can be adjusted and varied while X is the unknown resistance the value of which is to be measured The bridge is connected to a battery of 4 volts and a galvanometer, as shown in the figure Rh is a rheostat kept in series with the galvanometer to protect it from damage resulting from the flow of large currents. K_2 is just a tap-key which can be closed only for a very short period to understand whether the current flowing in the Galvanometer is giving a deflection beyond the full scale of the galvanometer or less. K_1 is a plug-key which can be kept rigidly closed.

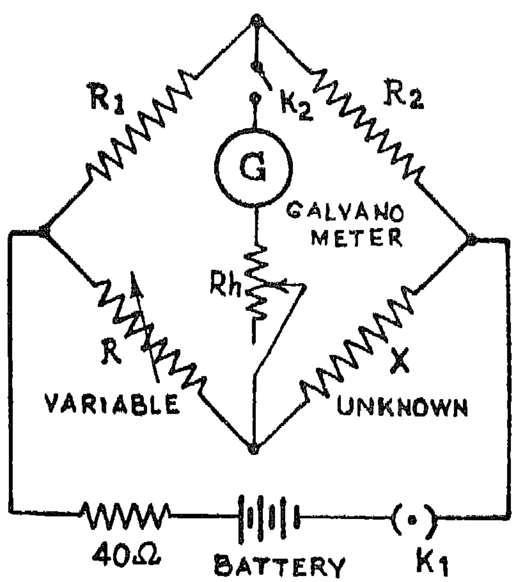


Fig. 8.17. Connections of a Wheatstone Bridge

$R_2 = R_1$ is chosen as 100 ohms and K_1 is closed. With the value of Rh kept at maximum i.e nearly 1000 ohms, K_1 is closed for a short time and the deflection of galvanometer is noted The value of R is adjusted until the deflection becomes zero. The value of Rh is reduced to zero, and again the value of R is varied by a very small amount only until the deflection is zero. The dial readings of R are noted and the value of X calculated from

$$\frac{X}{R} = \frac{R_2}{R_1}$$

The same process is repeated by keeping $R^2 f = 1000$ ohms and $R_1 = 100$ ohms. X is calculated. Thus it may be seen that proper choice of the ratio of $\frac{R_2}{R_1}$, enables measurement of large or small value of X.

Another form of Wheatstone Bridge, known as 'slide-wire' or 'metre' bridge, is shown in Fig. 8.18 Here R is a fixed known resistance, and X is the unknown resistance to be measured. The points at one end of these resistances are joined together and connected to one terminal of a galvanometer.

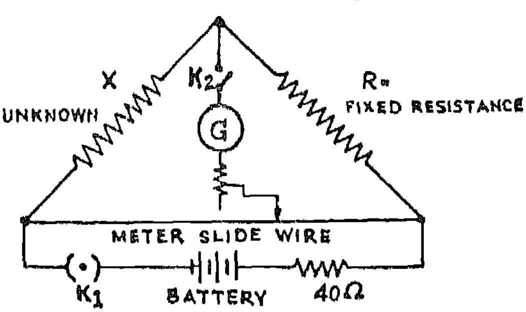


Fig. 8.18 Connections of a Metre Bridge

The points at the other end of the two resistances are joined by a wire one metre long The other end of the galvanometer is connected to a sliding contact which can move over the slide-wire from its one end to the other. The sliding contact is moved until the galvanometer shows zero deflection. If this condition is obtained when the contact is d mm. from the end connected to X, then

$$\frac{X}{R} = \frac{d}{1000-d}$$

from which

$$X = R\frac{d}{1000-d}.$$

If R is in ohms, X will also be obtained in ohms

Ammeter-voltmeter Method

By this method, the unknown resistance X is connected in series with an ammeter and a rheostat to a battery, as shown in Fig. 8.19. A voltmeter is connected across the unknown resistance X. Then, from Ohm's Law, the voltmeter reading V, which is the voltage drop across X is equal to the product of current in the circuit I, as indicated by the ammeter, and the resistance X, or

$$V = IX$$

from which

$$X = \frac{V}{I}.$$

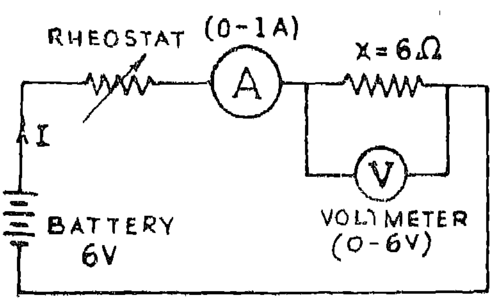


Fig. 8.19. Measurement of Resistance by Ammeter-voltmeter Method

If V is in volts, and I in amperes, then X will be in ohms. Ammeter-voltmeter method ensures the measurement of X quicker than the earlier methods but gives only approximate value for X.

8-15. Connection of Instruments

The methods of connection of the various measuring instruments are very important. If the instruments are not connected properly, they may be damaged, or wrong results obtained.

Ammeter

While connecting ammeters for measuring current in any circuit, care has to be taken regarding the range and polarity of the instrument. The current to be expected in the circuit must be within the range of the instrument If the current exceeds the range considerably, the instrument coil will get burnt. The polarity is important when the measurement is made in a D C. circuit. A D.C ammeter has the polarity marked on its terminals as + (positive) and —(negative) or any one of them. While connecting the instrument, these terminals are connected to the corresponding sides of the circuit as shown in Fig 8 20. If the polarities are reversed, the instrument will tend to read in the opposite direction But since there is no space for the pointer to move in the reversed direction, it will hit a buffer and may break.

Voltmeter

All the care necessary for ammeters must also be taken in the case of voltmeters.

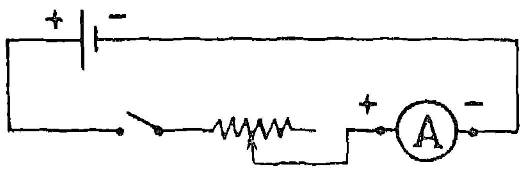
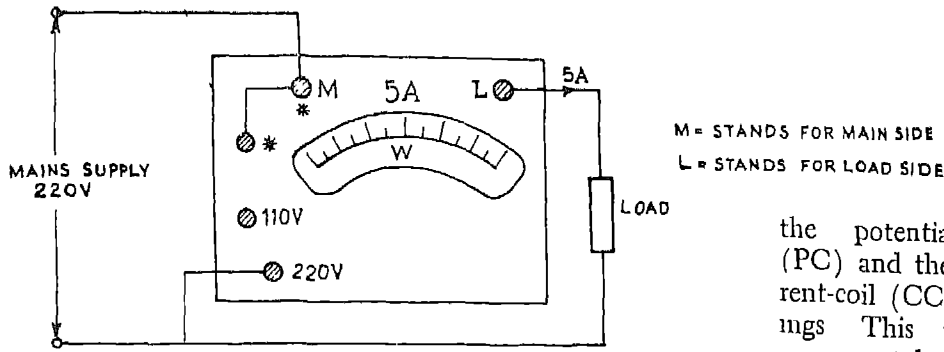


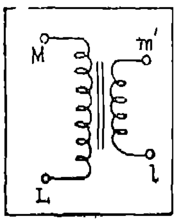
Fig. 8.20. Connections to Proper Polarity of an Ammeter

Wattmeter

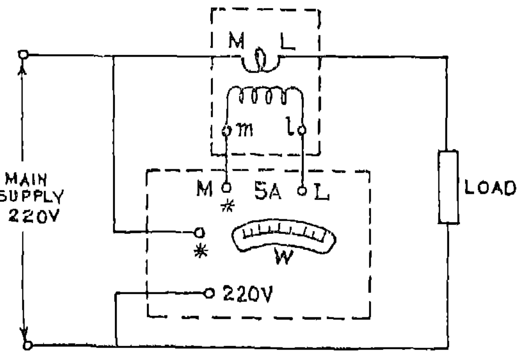
Every wattmeter, both in D C. and A C circuits, has current—and potential—coils. Both these coils have specified ratings. The current coils may have ratings of 2 5, 5 or 10 amperes, and the potential coils 110 or 220 volts. Also, the current and potential coils must be connected to the circuit according to a given polarity, which is usually marked on the terminals or indicated by a connection diagram at a convenient point in the instrument If a wattmeter has provision for multi-range working, separate terminals are provided for the corresponding ranges, and corresponding 'multiplication-factors' are also given somewhere on the instrument. The scale-reading of the instrument must be multiplied by this factor to obtain the true power If the current and voltage exceed the specified ranges in A C circuits, the same wattmeter can still be used with other accessories To bring the current within the range, a 'current-transformer' is used, and for voltage a 'potential transformer' to bring down the voltage suitable for the potential coil. The arrangement is shown in Figs 8.21(a) and (b). These types of diagrams are also given on the instrument by the manufacturers To get the actual power in the circuit, first the scale-reading should be multiplied by the multiplying factor corresponding to



WATTMETER CONNECTIONS (WITHOUT C.T.)

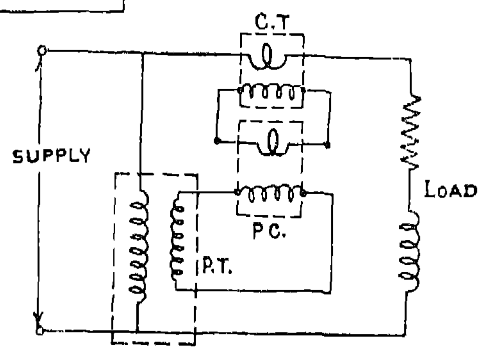


CURRENT TRANSFORMER MARKINGS



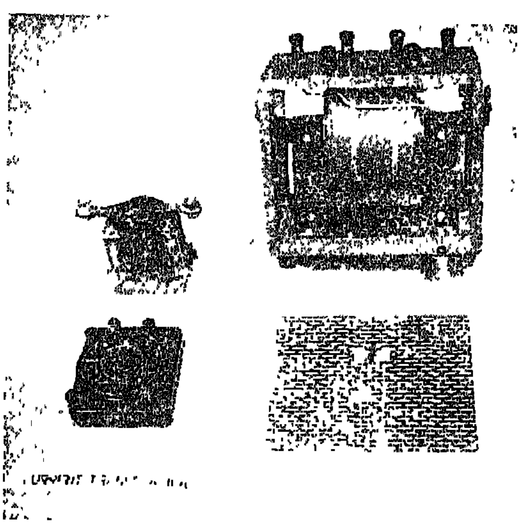
(a)

the potential-coil (PC) and the current-coil (CC) ratings This result now must be multiplied by the transformation ratios of both the current transformer (CT) and the potential transformer (PT). Then the actual power consumed in the circuit will be obtained.



(b)

Fig. 8.21. Connections of Wattmeter with C.T. and P.T



A Potential Transformer and a Current Transformer

Energymeter

Study of a single-phase house-service meter

The construction and fitting of the following parts of the instrument are to be studied·

(1) Shunt-magnet core and its winding;

(ii) Series-magnet core and its winding;
(iii) Power-factor compensator;
(iv) The friction compensator;
(v) The gear train and the dial mechanism;
(vi) The terminals and their markings.

Fig. 8 22 shows the terminals and connections of an A.C. single-phase energymeter The meter can be connected to the supply of rated voltage, and a load of, say, 100 W lamp may be connected across the load terminals. If the load is allowed to be on for one hour, then the energy consumed will be 100 watt-hours which is equal to $\frac{1}{10}$ Kwh. The readings obtained in the meter may be checked If the meter reads more than $\frac{1}{10}$ Kwh., it is running faster, and if less it is running slower This may be corrected by adjusting the friction compensator. After switching off the lamp-load, a choke coil of known wattage may be connected as load and the meter-reading checked as before. If the meter now reads wrongly, the power-factor compensator may be adjusted and experiment repeated a number of times to get the correct reading This can be done for different choke coils of different power-factors. The house-service meters are made for 5 amp. or 10 amp. current-rating. While using the current rating must be checked carefully before connecting a load The terminals also must be connected according to their markings.

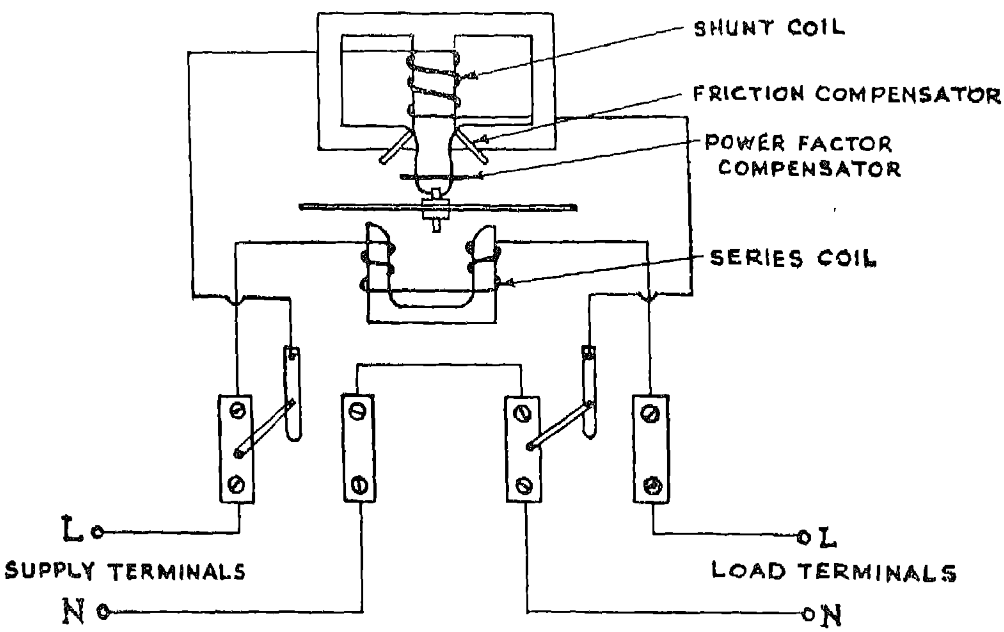


Fig. 8.22. Terminals and Connections of an Energymeter

APPENDIX

Historical Landmarks in Electrical Engineering

SOME simple facts about electricity were known as early as about B.C. 600. A Greek philosopher named Thales noticed that a bird's feather was attracted to a hard, reddish-yellow substance called *amber*, when the substance had been rubbed against another piece of material In 62 A.D a Roman teacher and scientist, named Pliny, noted that this attraction of amber was very much like the attraction of *loadstones* or *pointing ores* Loadstones used to point to the earth's N-pole when hung by a string or placed on a piece of wood floating in water This ultimately resulted in the development of the *magnetic compass* However, these facts could not stir much curiosity till the beginning of the fourteenth century when men of science in the West started striving, in a more definite manner, to delve into the mystery of electricity. In 1600 William Gilbert of England, the father of electricity, gave for the first time the name *electricity* to the attraction of light, dry material to amber (the word amber has been derived from its Greek synonym *elektron*) Subsequently at about the turn of the eighteenth century, the properties of *attraction* and *repulsion* between electrified objects were noticed Electrified bodies were said to be charged For the purpose of easy identification one kind of electrically charged bodies was called *positive* and the other kind *negative* Benjamin Franklin (1706-1790) of America found by experimenting with kites, sent high into the air, that lightning acted like electricity and that clouds had positive or negative charges of electricity like the charged bodies on earth He also made lightning rods for protecting buildings from lightning strokes, which we use to this day. Henry Cavendish (1731-1810) of England showed that iron wires were 400 million times more conducting than pure water. The first *electric current* was invented in 1800 by Alessandro Volta (1745-1827) of Italy by touching together two pieces of wire from piles of two unlike substances in an acid solution Those substances were copper and zinc This fact ultimately resulted in the development of the cells and batteries as we see them today. Events moved very fast after that and, in 1815, Sir Humphrey Davy (1778-1829) of England invented the famous safety lamps for miners which anticipated the discovery of the electrtic light bulb later. In 1819 Professor Hans Christian Oersted (1777-1851), a Danish

scientist, discovered movements of magnetic needle near a wire carrying electric current and also formulated the laws governing the movement This discovery led to the development of the subject known as *electromagnetism*. The first electromagnet was invented by William Sturgeon of England in 1815 Andre Marie Ampere (1775-1836), a French physicist, discovered more facts about electromagnetism, and the measuring unit of current has been named Ampere in his honour. Michael Faraday (1791-1867) of England discovered a second kind of electric current. He found that the relative motion of a closed conductor in a magnetic field resulted in current in the conductor The principle is called *electromagnetic induction* All the modern generators of electricity and electric motor work are based on this principle. Joseph Henry (1797-1878) of America, a contemporary of Faraday, worked on electromagnetic induction and discovered *self-induction* in conductors carrying current. The unit of measurement for inductance has been named after him and is called *henry*. A German physicist, George Simon Ohm (1787-1854), discovered some fundamental rules about flow of electricity through resistance. They are the well-known *Ohm's law*. John Dalton (1766-1844) discovered in about 1803 that all materials were composed of small particles called atoms. This idea later developed into the *atomic theory* which helped scientists in explaining some of the phenomena connected with electricity. Clerk Maxwell (1831-1879) of Scotland gave his ideas in the form of mathematical formulae stating that electricity could cause electric waves of some sort in air. The theory of electric waves in space was later extended by the German physicist Heinrich Rudolf Hertz (1857-1894). The *radio waves* are also called *hertizian waves*. In 1836 *telegraph* was invented by Samuel Morse (1791-1872) of America He made some codes to represent various numbers as well as letters of the alphabet This code, with some modifications, is known as the *Morse code* or the international code used today for communicating message. Alexander Graham Bell (1847-1922), also of America, invented the telephone in 1876, with the help of which people can talk to one another. The *electric bulbs* were invented by another American, Thomas Alva Edison (1847-1931), in 1886. They were used to light up Pearl Street in New York City. The Danish physicist Niels Bohr (1885-1962) showed that the atoms consisted of *Nucleus* and some *electrons* orbiting round it. This is known as the *electron theory*. He also indicated that certain atoms could be split to give out an enormous amount of energy. This principle ultimately led to the development of the *atom bomb* which destroyed two cities, Hiroshima and Nagasaki of Japan, during the Second World War Now atomic energy is used for peaceful purposes, the most important of them being the generation of electric power Hertz's electric waves led to the invention of *wireless* technology. Two persons who worked in this field simultaneously but independently of each other, were Sir Jagadish Chandra Bose (1858-1937) of India and Guglielmo Marconi (1874-1937) of Italy The credit went ultimately to Marconi, although Sir Jagadish Chandra Bose, too, was successful in making instruments capable of sending and receiving wireless or radio waves The sender is called the *Transmitter* while the apparatus receiving the signals is called the *Receiver*

With James Ambrose Leming (1849-1945) of England, Marconi developed the *electron or vacuum tubes* used in the radio and television circuits The first message across the ocean, from Great Britain to Newfoundland, was received in 1901 by Marconi. Dr. Lee De Forest (1873-1961) developed the first broadcasting system in the USA. The American inventor, Edwin H. Armstrong (1890-1954), made many improvements on radio communication. Television was invented by V. K Znorykin (1889-), an American physicist, in 1928 by which pictures could be transmitted by wireless technique. The principle underlying this is that variation of light intensity on some substances can cause variation in the current flowing through it. This principle is also utilised in *exposure meter* used in photography. The *transistor* is one of the most recent developments It is also called a semi-conductor, because it allows current to flow under certain conditions only A Brittain of the Bell Telephone Laboratories of the USA made important discoveries in this field in 1946 Transistors can be used in radio and television sets in place of vacuum tubes. The semi-conductors have come into the field of electrical engineering with great promise; and future years are sure to be marked by many important developments